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NUMERICAL COMPUTATION OF RING-SYMMETRIC
SPACECRAFT EXHAUST PLUMES

by

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ABSTRACT

This report supplements report NPS72-86-003CR. It provides further details about the code JET and the numerical schemes on which it is based: inverse marching characteristic and semi-inverse marching characteristic (SIMA) schemes. The computational procedure is described in some detail. The principles of operation of the code JET are outlined, including a glossary of all major arrays, variables and subroutines. Finally, the full listing of the JET code is reproduced.

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NOMENCLATURE followed by units (if any) and CODE NOTATION (if any)

```
sound speed (m sec<sup>-1</sup>)
a
         breakdown parameter [5,6,7]
В
c^{\pm}
         characteristic lines inclined at (\theta \pm \mu)
         molecular diameter (hard spheres) (m)
D
         Mach number
M
         number density (molecules/m<sup>3</sup>)
n
         pressure (Pa)
p
         coordinate along streamlines (m)
S
         flow velocity (m/sec)
u
         axial cartesian coordinate
\mathbf{X}
         radial cartesian coordinate
y
         specific-heat ratio (G)
γ
         length coordinate along fan characteristics (C<sup>+</sup>) (m)
η
         inclination of flow velocity vector
θ
         mean free path at stagnation conditions (m)
\lambda_0
         Mach angle (\sin \mu = 1/M) (MU)
μ
         Prandtl-Meyer function (NU)
ν
         length coordinate along transverse (C<sup>-</sup>) characteristic
         collision cross-section \pi D^2 (m<sup>2</sup>) (SIGMA)
σ
         molecular opacity (expected number of collisions by a fast invading molecule) (XI)
τ
         collision frequency (sec<sup>-1</sup>)
φ
         symmetry index (0 - planar flow, 1 - axisymmetric flow) (DELTA)
ω
         the fraction [(\gamma+1)/(\gamma-1)]^{1/2}
Γ
(v + \theta) Riemann invariant along C (RM)
(v - \theta) Riemann invariant along C<sup>+</sup> (RP)
```

INDICES

()₀ a specific point in the CRW (x₀,y₀) (Also: stagnation conditions)
 ()₁ nozzle exit conditions
 ()_L limiting CRW characteristic (p=0)
 ()_f final CRW characteristic (boundary of numerical integration)
 ()_c corner of CRW

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1. INTRODUCTION

In a recent report [1] a mixed numerical/analytical approach to the computation of a ring-symmetric spacecraft exhaust plume was presented. The numerical scheme had been implemented in a code named "JET" which is capable of generating whole-plume flow fields, while the analytic approximation is restricted to the ring-symmetric centered rarefaction waves (CRW) that flank the plume. The present report is intended to serve as a supplement to [1] in providing details on the computational scheme and the code JET.

The spacecraft exhaust flow (Fig. 1 of [1]) is idealized as a ring-symmetric steady isentropic expansion of an ideal gas. The nozzle lips are assumed sharp; the supersonic flow from the exit surface of the ring-nozzle is assumed uniform, and the background is considered to be perfect vacuum.

The standard scheme for computing such idealized ring-plumes is the classical (direct) method of characteristics [2]. At a preliminary phase of the present laser exhaust study, a code AXSYM [3] was written for computing ring-plumes using this method. A notorious shortcoming of the direct method of characteristics is that the solution grid is highly irregular, being formed by the (oblique) intersection of the C⁺ and the C⁻ families of characteristic lines. We first encountered a difficulty with this grid while seeking a scheme for integrating the molecular opacity along a straight line [1]. This computation would have required rather complex coding for the geometry of intersection between a straight line and an irregular grid. It seemed preferable to opt for a computation scheme that would produce a more regular grid, even at the expense of some loss of accuracy. Such scheme is the inverse marching method of characteristics [4].

Generally the marching in this type of scheme is in the downstream direction, i.e., the y direction in our case. Grid points are located on a succession of constant-y rows, thereby introducing a measure of regularity in the solution grid. Just two rows have to be stored in the computer core memory - the "old" row and the "new" row, whereas in the direct method of characteristics whole grid-image matrices are required to reside simultaneously in core memory.

The first version of the JET code was based on the inverse marching scheme given by Zucrow and Hoffman (Section 12-5 in [4]), where the flow variables were the *two cartesian velocity components*. The computation seemed accurate everywhere, except within the centered rarefaction wave (CRW). In an attempt to replicate a planar CRW (Prandtl-Meyer flow), the numerical solution exhibited an

instability: Mach number increased along the (low pressure) boundary characteristic line, rather than remain constant.

A *qualitative* explanation for this instability is the following. Flow gradients in a CRW are inversely proportional to distance from the corner, so that the inverse marching scheme gives rise to an amplification of interpolation errors at every marching step, leading to an apparently divergent (unstable) numerical solution. Increasing the order of interpolation from linear to cubic did not eliminate the instability.

Looking for a scheme that would replicate a planar CRW accurately, we tried the modified marching idea as presented by Zucrow and Hoffman for 1-D time-dependent flows (Sections 19-6(a) and 19-6(j) of [4]). In this scheme new grid points are determined by forwardly extending a "primary" family of continuous characteristic lines from old grid points. The primary family in a CRW is the characteristics fanning out from the corner (we assume it is the C⁺ family). By choosing this modified scheme, the interpolation for trace points obtained from reversely extended C⁺ lines was eliminated. However, the corresponding interpolation for the transverse C⁻ characteristics remained, and with it the aforementioned instability.

In order to replicate a planar CRW, we had to replace the flow variables by the *Riemann invariants* $(v \pm \theta)$. In a C^+ planar CRW, the Riemann invariant $(v + \theta)$ is uniformly constant, so that the interpolation in $(v + \theta)$ due to reversely extending C^- characteristics introduces no error at all. This scheme, which we named SIMA (Semi Inverse Marching Algorithm), was indeed verified to replicate a planar CRW exactly, when implemented in the code JET.

The plan of this report is the following. In Ch. 2 we supplement the description of the numerical scheme given in Ch. 2 of [1], by adding more details on the computational procedure. A description of the code JET is given in Ch. 3, and the code listing is reproduced in Ch. 4.

Note on symmetry:

The code JET has two symmetry options. When DELTA = 1 a ring-symmetry is in effect; when DELTA = 0, a planar symmetry is in effect. An axisymmetric jet exiting in the y direction from the same nozzle aperture along the x axis can readily be computed by replacing all terms in the code that correspond to $\sin(\theta)/y$ in the compatibility equations (2.1-1), by $\cos(\theta)/x$. In that case the coding is virtually unchanged, and the only care that should be exercised is for the difference equations for new grid points on or near the y axis. Also, all reference to the analytic approximation of the ring-symmetric CRW [1] should be deleted in this case, as it is designed specifically for ring-symmetry.

2. THE COMPUTATIONAL SCHEME

A basic description of the semi inverse (SIMA) and inverse marching schemes was given in Ch. 2 of [1]. We supplement this description by specifying the slightly modified definition of Riemann invariants in the code, and by giving information about some ancillary computations.

2.1 Riemann Invariants

The compatibility equations whose integration constitutes the numerical solution to the governing equations [1] are expressed in terms of the Riemann invariants as follows:

Along
$$C^+$$
 $(v - \theta)_4 = (v - \theta)_2 + \omega \sin \mu_{24} \sin \theta_{24} \Delta \eta / y_{24}$

Along C^- $(v + \theta)_4 = (v + \theta)_1 + \omega \sin \mu_{14} \sin \theta_{14} \Delta \xi / y_{14}$

(2.1-1)

The Riemann invariants $(v \pm \theta)$ are modified for convenience, by adding a constant to both v and θ . The new definitions of v(M) and θ are:

$$v(M) = -\Gamma \arctan(\Gamma q) + \arctan(q)$$

$$q = (M^2 - 1)^{-1/2}$$

$$\theta \to \theta - \theta_T$$
(2.1-2)

Thus, in a Prandtl-Meyer flow with entry Mach number of M_1 , the modified values of both v(M) and θ vanish as $M \to \infty$. As a consequence, in a C^+ Prandtl-Meyer flow the modified invariant $(v + \theta)$ vanishes uniformly. In this modified form, the computation of M from v(M) is readily done by performing standard Newton-Raphson iterations (in RFUNC), using the derivative:

$$\mathbf{v}'(\mathbf{q}) = -(\Gamma^2 - 1) \left[(1 + \Gamma^2 \mathbf{q}^2)(1 + \mathbf{q}^2) \right]^{-1}$$
 (2.1-3)

2.2 The Integration Scheme for a New Grid Point

The integration scheme has been sketched in Ch. 2 of [1]. It is performed in INVMAR for inverse marching points or in SEMINV for semi-inverse marching (SIMA) points. The computational scheme is specified via the following seven-step procedure:

INVMAR (Inverse Marching)

- (a) Grid: At this stage the new grid point has already been defined.
- (b) Predictor: Flow variables are the interpolated (linear nearest-neighbor) value on the old row for a point having the new grid x coordinate (x_a) .
- (c) Centered variables: Denote the Riemann invariants by

$$RM = (\nu + \theta)$$

$$RP = (\nu - \theta)$$
(2.2-1)

then centered values for segments (1,4) and (2,4) (using code notation) are:

$$RM14 = (RM1 + RM4)/2$$
 $RP14 = (RP1 + RP4)/2$ (2.2-2)
 $RM24 = (RM2 + RM4)/2$ $RP24 = (RP2 + RP4)/2$

All other centered flow variables are computed from the centered Riemann invariants by calling RFUNC.

(d) Inverse Extension: old trace points x_1 , x_2 are evaluated from the geometrical relations

Along
$$C^-$$
 $y_{\text{new}} - y_{\text{old}} = (x_4 - x_1) \tan(\theta_{14} - \mu_{14})$
Along C^+ $y_{\text{new}} - y_{\text{old}} = (x_4 - x_2) \tan(\theta_{24} + \mu_{24})$ (2.2-3)

- (e) Interpolation: find Riemann invariants RM, RP at old trace points x_1 and x_2 through nearest-neighbor linear interpolation by calling INTERP.
- (f) Integration: Using the compatibility relations in finite-difference form (2.1-1) with segment-centered coefficients, compute iteration-updated values of Riemann invariants at new grid point.

(g) Corrector: if values of Riemann invariants and old trace points x_1 , x_2 are not sufficiently convergent, resume the procedure at step (c) above.

SEMINV (Semi Inverse Marching - SIMA)

- (a) Grid: New grid point (X_4) is determined as part of the SIMA scheme at step (d) below.
- (b) Predictor: Flow variables are those of point (x_2, y_{old}) .
- (c) Centered variables: Identical to step (c) above.
- (d) Semi-Inverse Extension: new grid point x_4 and old trace point x_1 are evaluated from the geometrical relations in Eq. (2.2-3) above.
- (e) Interpolation: find Riemann invariants RM, RP at old trace point x_1 through nearest-neighbor linear interpolation by calling INTERP.
- (f) Integration: Identical to step (f) above.
- (g) Corrector: Identical to step (g) above, except for replacing x_2 in the convergence test by x_4 .

2.3 Boundary Conditions

On the vacuum side the boundary conditions (p=0) can only be approximately implemented in a method of characteristics scheme. We do so by ending the computation on a certain "final" C^+ fan characteristic line that starts out with a sufficiently high Mach number M_f at the corner (typically $M_f=34$). The marching computation of new grid points on the boundary C^+ characteristic via the SIMA scheme is identical to that of C^+ characteristics within the ring-symmetric CRW. It is noted that under this boundary scheme some outflow takes place through the boundary characteristic line, so that the total mass flow through a row $y=y_{new}$ decreases slightly as y_{new} increases.

At the nozzle exit the boundary conditions are assumed to be uniform outflow in the radial (y) direction with Mach number M_1 . At the nozzle lip, the SIMA integration starts out from a presumed planar CRW (Prandtl-Meyer flow) at the corner (i.e., the associate CRW in the terminology of Ch. 3 in [1]).

At the plane of symmetry (x=0) the boundary condition is simply $\theta=\pi/2$. However, this condition is implemented indirectly, by assuming that the flow at virtual grid points with x<0 is a mirror-image of the flow at the corresponding x>0 points. The reason is that when a new grid point of $x_4=0$ or of x_4 sufficiently close to zero is considered for inverse-marching integration, the inversely extended trace point (x_1,y_{old}) can be at x<0. Considering the subtraction of θ_L from θ as in Eq.(2.1-2), the reflection rules are:

$$RM \rightarrow RP + (\pi - 2\theta_L)$$

$$RP \rightarrow RM - (\pi - 2\theta_I)$$
(2.3-1)

where values on the left and right of the \rightarrow symbol correspond to values left and right of x = 0. This boundary condition is implemented in INTERP.

2.4 Continuum Breakdown Surface

As an informative option, the code JET can compute (in PLUMES) points on a surface of continuum breakdown [5,6,7], which is defined as a line of constant B, where B is given by:

$$B = -(u/\phi) \rho^{-1} (d\rho/dS)$$

$$\phi = 4(\pi\gamma)^{-1/2} \sigma n a$$
(2.4-1)

When the standard isentropic relations for ρ and n in terms of M are substituted in (2.4-1), the flow speed is expressed as u = Ma and the streamwise gradient of M is expressed in cartesian coordinates, we get:

$$B = \lambda_0 (\pi \gamma / 8)^{1/2} M^2 \left[1 + ((\gamma - 1)/2) M^2 \right]^{1/(\gamma - 1) - 1} \left[M_{\chi} \cos \theta + M_{y} \sin \theta \right]$$

$$\lambda_0 = \left(2^{1/2} \sigma n_0 \right)^{-1}$$
(2.4-2)

Note that the sign of B has been chosen as positive for expansion flows. This definition is preferred to taking an absolute value of the flow gradient, since it assures proper interpolation of B even if its spatial distribution goes through B=0.

Due to the dependence of B on a spatial gradient, its numerical evaluation (see BREAK) is attributed to mid-grid points both in x and in y.

3. THE JET CODE

In this chapter we provide a concise description of the JET code according to its version at the time of the JET018 run. This description is intended as an aid in reading the code listing which is given in Ch. 4.

The plan of this chapter is as follows. Array variables that constitute the mainstay of the computational scheme are described in Section 3.1. Auxiliary array variables that are used primarily for processing the information generated by the numerical scheme, are described in Section 3.2, followed in Section 3.3 by a list of major parameters that control the computation (some of them also serve as run data). Finally, all subroutines are listed and described in Section 3.4.

3.1 Main Variables

The array variables used for the computational scheme are organized in two labeled COMMON groups. The first group /VECS/ is designed to hold two grid rows - the old row designated by suffix F and the new row designated by suffix N. The second group /CHARAC/ are characteristic-indexed arrays that hold information about continuous characteristic lines. This characteristic information is used in two ways: it is incorporated in the SIMA computational scheme for the CRW region, and it is used to store data for optional plotting of characteristic lines (see PLUMES and PRINT).

The basic organization is that the new arrays (suffix N) are those in which values are stored during the course of the marching computational procedure. At the end of each marching step, values are transferred from new arrays to old arrays (suffix F); this is done in MOVE. In the array listing below, we indicate in parenthesis the subroutine (or subroutines) in which that new array is defined.

/VECS/ ·

XN(I)	x coordinate of grid point I. (GRIDN)
RMN(I)	modified Riemann invariant $(v + \theta)$ at grid point I. (BEGIN, INVMAR,
	LOADC).
RPN(I)	modified Riemann invariant $(v - \theta)$ at grid point I. (BEGIN, INVMAR,
	LOADC).
MN(I)	Mach number at grid point I (BEGIN, INVMAR, LOADC).
MUN(I)	Mach angle μ at grid point I. (BEGIN, INVMAR, LOADC).
TETAN(I)	true (unmodified) flow angle θ at grid point I. (BEGIN, INVMAR, LOADC).

- BN(I) value of breakdown parameter **B** at point I-1/2 (and at half a marching step back in **y** as well). (BREAK).
- XTEMP(I) used for auxiliary computation of I-1/2 grid points in PLUMES.

/CHARAC/

- XCHARN(KC) x coordinate of point on characteristic line number KC. (BEGIN, SEMINV, PLUMES).
- YCHARN(KC) y coordinate of point on characteristic line number KC. (BEGIN, SEMINV, PLUMES).
- RMCARN(KC) modified Riemann invariant $(v + \theta)$ of point on characteristic line number KC. (BEGIN, SEMINV).
- RPCARN(KC) modified Riemann invariant $(v \theta)$ of point on characteristic line number KC. (BEGIN, SEMINV).
- TCHARN(KC) true (unmodified) flow angle θ at point on characteristic line number KC. (BEGIN, SEMINV).
- MUCARN(KC) Mach angle μ at point on characteristic line number KC. (BEGIN, SEMINV).
- CSIGNN(KC) sign of characteristic line number KC. It has value 1 for C^+ and value -1 for C^- . Note that upon reflection of a C^+ line from the symmetry plane (x=0), the sign value is changed from 1 to -1. (BEGIN, SEMINV).
- MCHARN(KC) Mach number at point on characteristic line number KC. (BEGIN, SEMINV).
- MCHARI(KC) Mach number at Prandtl-Meyer's fan characteristic number KC at the corner. It is defined initially and is not changed during the run. (BEGIN).

3.2 Auxiliary Variables

In addition to the major arrays mentioned above, there are several groups of auxiliary arrays that do not affect the computational scheme, but are intended for informative processing of the results. These groups are /PLUME/, /IPLUME/, /THICKY/, /THICKX/, /GRP/. /PLUME/ is used to preserve points on special lines for later plotting (in a separate code). /THICKY/ and /THICKX/ are for storing values of radial (y) and lateral (x) molecular opacities. The group /GRP/ is used in conjunction with comparative computation of the ring-symmetric CRW flow according to the analytic approximation [1].

/PLUME/ (PLUMES, PRINT)

XPL(J,IPL) x coordinate at marching step J of special line number IPL.

YPL(J,IPL) y coordinate at marching step J of special line number IPL.

/IPLUME/ (PLUMES, PRINT)

KPL number of special lines computed in PLUMES.

ITYPL(IPL) index indicating the type of special line number IPL.

/THICKY/ (OPACY, PRINT)

XTH(J) x coordinate on boundary characteristic line at marching step J, from which

radial opacity is integrated.

TH(J) radial opacity computed by y-integration from the boundary point defined by

XTH(J) (up to current YN).

/THICKX/ (OPACX, PLUMES, PRINT)

YXI(JXI) y coordinate of printed row number JXI (the index JXI counts just rows that

have been printed). The row to be printed next upon calling PRINT is the row

having YF near YXI(JXI).

XI(I,JXI) lateral (x) molecular opacity [1] at point XF(I), for printed row JXI. It is

obtained by numerically integrating the solution obtained from the JET

computation (see OPACX).

XIPM(I,JXI) same as XI(I,JXI) except that the Prandtl-Meyer solution is used to estimate

the flow at grid points XF(I).

XIGRP(I,JXI) same as above, except that the analytic approximation to a ring-symmetric

CRW [1] is used to estimate the flow at grid points XF(I).

XIAPP(I,JXI) same as XIGRP(I,JXI) except that the numerical integration is replaced by an

approximate closed-form expression [1].

XIF(I,JXI) stores grid points XF(I) of printed row JXI.

/GRP/ (PRINT, HMSET, MFUNC, HINTER, MATCH)

DMINV increment of inverse Mach number for array MHINV(I).

MHINV(I) inverse Mach number array (from 0 to 1/MEXIT), from which the H(M)

function can be evaluated (HMSET).

HMV(I) values of the H(M) function evaluated by numerical integration. It is used to

compute this function by interpolation. (HMSET, HINTER).

3.3 Major Parameters

Parameters that define and control a particular run (such as the maximum y for the marching computation, the number of grid points on a row and many more) are defined in INIDAT. (The code JET has no input file and no READ statements). The major control parameters are grouped in /PAR/ (floating point) and in /IPAR/ (integers); thermodynamic data are grouped in /STAG/.

We indicate in the listing the subroutines in which the labeled COMMON group or a particular parameter is defined (or sometimes referred to).

/PAR/ (INIDAT)

MEXIT nozzle exit Mach number (M_1) .

MFIN Mach number of the final (boundary) CRW characteristic at the corner (M_c) .

YMAX maximum value of y for the marching scheme. When YF.GE.YMAX the run is

terminated.

DY0 initial marching step.

DY current marching step.

DYNEXT next marching step (YSTEP).

STAB stability coefficient for marching step (STAB.LE.1). (See YSTEP).

DELTA symmetry index. DELTA = 0 for plane symmetry; DELTA = 1 for ring-symmetry.

PSII angle of Prandtl-Meyer fan characteristic at exit conditions (measured from x

axis).

PSIF angle of final (boundary) Prandtl-Meyer fan characteristic.

SIGMA collision cross-section (σ).

FRACG the number of intervals initially allocated to the CRW fan is a FRACG fraction of

the total number of intervals (KF0-1). (see BEGIN).

EPSIL convergence parameter (small number). (INVMAR, SEMINV).

TETLIM flow angle (from x axis) of the limiting (p = 0) velocity vector of the flow at the lip-

centered Prandtl-Meyer fan.

TETSYM PAI-2*TETLIM for reflection transformation (see INTERP).

/IPAR/ (INIDAT)

JMAX maximum number of marching steps. If J.GE.JMAX run is terminated.

KF0 initial (and maximum) number of grid points in a row.

KF current number of grid points in the old row.

KN current number of grid points in the new row.

ITER0 maximum number of iterations for the integration of the compatibility relations

(see INVMAR and SEMINV; also used in RFUNC, PLUMES).

IM, IP search indices for interpolation subroutine INTERP. (see INVMAR, SEMINV).

J current row index (also index of a marching step).

KF2 defined as 2*KF; not used in present version.

IDEL, JDEL increments for printing grid point I and row J (see PRINT).

JYXI number of rows to be printed in a run.

JXI index of printing row, to be printed next (see PRINT).

ILEAD index I at the first grid point on current new row, where the SIMA integration

commences. Initially this point corresponds to the leading characteristic of the

CRW. (see GRIDN, BEGIN).

ILEADF value of ILEAD for current old row.

KCLEAD index in the characteristic array for the characteristic line that corresponds to the

new grid point I = ILEAD (see GRIDN). Initially KCLEAD = 1.

/STAG/ (INIDAT)

RHO0, NO stagnation density and number density.

P0, T0, A0 stagnation pressure, temperature and sound speed.

MDOT1 mass flow rate from ring-nozzle (only from the x > 0 half). (See PRINT).

/ICHARA/ (BEGIN)

KCHARP number of C⁺ characteristic lines for which data is stored (either for SIMA computation or for subsequent plotting).

KCHARM number of C characteristic lines for which data is stored (only for subsequent plotting).

KCHAR0 total number of characteristics for which data is stored, i.e., KCHAR0 = KCHARP + KCHARM.

3.4 Description of JET subroutines

MAIN PROGRAM

The main program performs two functions. The first section (up to statement 1) is the initial set up; it is performed just once. The second section is the marching loop with the step index J. This program can be read as a flow chart of the overall computational procedure.

INIDAT is for setting up run data. In BEGIN the initial conditions for the marching computation are set up. A single marching step is performed by calling MARCH, and the loading of new row vectors into old row vectors is done by calling MOVE. The call to YSTEP is for the first computed marching step. All remaining calls are for informative tasks (see HMSET, BREAK, OPACY, PLUMES, PRINT). Run is terminated when either YF.GE.YMAX or when J.GE.JMAX.

NOTE ON EXEC: The only special feature in the EXEC is retaining the output unit 7 file for optional post-plotting. The printed output (unit 6) is the system's standard (default).

INIDAT

Initial data definition and preliminary data computations. The data is defined by statements rather than by reading an input file. The meaning of major parameters was described in Section 3.3 above. User is invited to modify the data definitions, particularly of run-control parameters such as YMAX, JYXI and YXI(JXI) (for printing JYXI selected rows).

BEGIN

Here all initial values (prior to beginning of marching schemes integration) are loaded into all major computational arrays (Section 3.1). Also, values of the key integer parameters KCHARP, KCHARM, KCHARO, ILEAD, KCLEAD and KF are defined.

In the first loop (loop 1) we define an initial family of C⁺ characteristic lines for the lip-centered CRW, by storing the Mach number of the Prandtl-Meyer fan characteristics in the array

MCHARI(KC). Note that the fan characteristics are generated at equal RP intervals, since the flow variables are RM and RP. However, a different division might also be acceptable.

The next step is the definition of initial values for all characteristic arrays, first the C^+ arrays (loop 2), then the C^- arrays (loop 21). The C^- characteristic lines are needed just for informative output (post-plotting), so the present version contains just one C^- line. The user may modify that.

The remaining grid points (altogether KF0 grid points are initially available) are uniformly distributed across the nozzle opening, and the row arrays are loaded with the corresponding nozzle-exit flow variables (loop 3).

PRINT

The main task of this subroutine is the printing of flow variables at grid points of selected rows. The printing of a row is selected when YF is close to a predefined array YXI(JXI). Following the printing, JXI is updated by adding 1.

For comparison, additional flow variables are printed for each row. These are computed from the analytic approximation to a ring-symmetric CRW [1], by calling MATCH. Also, lateral molecular opacities of various kinds of approximation are computed by calling OPACX, and are printed for each grid point within the CRW.

Following the row printing (statement 120), arrays intended for post-processing (plotting of special lines) are printed and subsequently written on output unit 7. This is done once per run, just before run termination.

FIN

This subroutine is called when an error is encountered, in order to terminate the run. Note that the run is terminated by deliberately introducing an error of computing SQRT(-1), which is done in order to trigger the printing of calling sequences by the operating system.

MARCH

This subroutine performs a single marching step by calling the proper computational subroutines at an appropriate sequence. It can be read as a flow chart of the entire computational scheme. First the segment of the new row suitable for SIMA computation is calculated by calling SEMINV. Then new grid points for that part of the new row for which inverse marching integration is to be performed, are generated by calling GRIDN. The results of the SEMINV computation, which were stored in characteristic arrays, are now loaded into row arrays by calling LOADC. Finally, the computation of the new row is completed by calling INVMAR which computes the flow at the remaining grid points by the inverse marching scheme.

INVMAR

This is one of the two central subroutines for computing the flow at new grid points (the other is SEMINV). Here the inverse marching scheme is used. The computational procedure follows the seven-step description given in Section 2.2 above. Note that the initial value of the search indices IM and IP is not redefined at each call to INTERP, since it is assumed that IM and IP do not change much at consecutive calls to INTERP, so that search efficiency is enhanced by not starting the search from an arbitrary point (such as either end of the row).

SEMINV

This is the subroutine performing the SIMA scheme for computing the flow at new grid points located along continuous characteristic lines of the lip-centered CRW (at prescribed y-marching steps). The essence of the computational procedure of this subroutine was given as a seven-step description in Section 2.2. The same remark about IM given in the preceding INVMAR description applies here as well.

The main loop (100) is over all characteristic lines, including some C^- lines in addition to the C^+ lines. Thus, the array CSIGNF(KC) is used to get the appropriate expressions for either C^+ or C^- characteristics. It is noted that while normally the characteristic segments through points 1 and 2 are C^- and C^+ respectively, this is reversed when a C^- rather than a C^+ line is computed via the SIMA scheme. In this case, which is characterized by having CSIGNF(KC).LT.0, the Riemann

invariants integrated along segments (1,4) and (2,4) are interchanged. This is done in the few statements just preceding and following statement 21.

An additional capability of this subroutine is to treat a change of a C^+ characteristic line into a C^- line upon reflection from the symmetry plane (x=0). This is done by first computing a new grid point having X4.LT.0, and then changing its sign after setting CSIGNN(KC) = -1 (statements just preceding statement 30). It is also possible to skip the computation of a particular characteristic by setting CSIGNN(KC) = 0. This feature is not exploited in the present version.

Finally, we note that not all characteristic lines computed here are part of the marching flow computation. Only those with indices KC between KCLEAD and KCHARP are. All other characteristic lines are computed just for informative purposes (post-plotting).

RFUNC

Here M, MU, TETA are computed from the two Riemann invariants RM, RP. The computation of M is performed by a Newton-Raphson iteration using Equations (2.1-2) and (2.1-3) given in Section 2.1 above.

INTERP

This subroutine starts by finding through a search procedure the grid interval (I, I+1) that contains a given point X. Then the Riemann invariants are computed for this point by linear interpolation, and returned in RM, RP. Note that X may be negative, which accounts for the relatively elaborate search logic in the determination of I, and for the reflection transformation (as in Eq. (2.3-1) above) preceding the last two statements of the subroutine.

INTERX

This interpolation routine performs an inverse task to that of INTERP, in that it finds the point X0 that corresponds to a given linearly interpolated value of the flow variable VAR0. It is used in PLUMES to compute the location of a breakdown surface point on a new row of x-centered and y-centered grid points

BREAK

This subroutine computes the new breakdown parameter array BN(I). The computation is based on the description given in Section 2.4 above.

OPACY

Here the radial (Y) molecular opacity array TH(J) is computed. At each marching step J, a new boundary grid point XTH(J) is added, then the radial opacities at all preceding boundary points are updated by adding the contribution of the gas layer between the current old and new rows. Note that since grid points on adjacent rows are not located on equal-x columns, this procedure requires x-interpolation by calling INTERP.

PLUMES

This is a user-defined subroutine, where up to 10 special lines can be computed and subsequently retained on output unit 7 for post-processing (plotting). The type of the line ITYPL(IPL) and a parameter VPL(IPL) that defines the line, are computed through user-inserted statements in the section preceding statement 2000. Then an additional point on the current new row is computed for each line type. The available types are clearly stated in comments. Note that characteristic lines have already been computed in SEMINV using the SIMA scheme, regardless of whether they are part of the solution grid to the flow field, or are just computed for informative purpose. It is the user's choice which of these lines (if any) are to be saved in the /PLUME/ arrays for subsequent post-processing (plotting).

GRIDN

This subroutine computes the grid points in that segment of the new row for which the flow is computed by the inverse marching scheme (in INVMAR). Initially, this segment extends from x=0 to the new row grid point which lies on the leading characteristic of the lip-centered CRW. However, since the leading characteristic is reflected from the symmetry plane (x=0) at some point, this segment steadily shrinks in size as the marching proceeds. The remedy is to declare the next-to-the-

leading characteristic line (KC=2) as the beginning of the segment for SIMA integration, by setting KCLEAD=2. This process of increasing KCLEAD is repeated whenever it is deemed necessary. The criterion in the present version for the minimal KCLEAD is that the inverse-marching segment should be at least twice DX1 - the average CRW grid interval (loop 1, the two statements following DX1=...). Also, ILEAD is redefined for each row according to XLEAD/DX1+2 in order to achieve a row of relatively uniform grid intervals throughout. The result is that the number of grid points in a row is initially KF0, but eventually it decreases due to both increase of KCLEAD and decrease of ILEAD.

YSTEP

In this subroutine the next marching step DYNEXT is computed at the end of the current marching step. It is defined as the smallest step obtained by forward intersection of C⁺ and C⁺ characteristics from adjacent grid points. Note that the actual value of DYNEXT is reduced by a "stability" factor STAB, and that DY is also limited by the growth-rate factor DDY and by DYMAX (see MAIN PROGRAM).

MOVE

Here old row arrays (loop 1) and old characteristic arrays (loop 2) are loaded with values of flow variables from corresponding new arrays, in preparation for the next marching step. As a result of this organizational feature, informative computations (e.g. BREAK, OPACY) that require both new and old rows, have to be performed prior to calling MOVE.

OPACX

Here lateral (X) opacities that correspond to the number of expected collisions of a fast molecule invading the CRW in the -X direction, are computed. All opacities, except XIAPP(I), are computed by numerical integration. In loop 1 we compute the opacity contribution of the segment lying just outside the computational boundary characteristic (MFIN), assuming a Prandtl-Meyer flow. This additional opacity is denoted XIO. If the flow is ring-symmetric, XIO is recalculated using the analytic approximation [1] to estimate the flow field at the fringes of the ring-symmetric CRW (see also the closed form expression for τ in [1]).

The computation of opacity arrays starts after statement 14. First, the opacity at each grid point is set to XIO. Thus, even though the numerical flow computation does not include the fluid outside the boundary characteristic line, the opacity integration includes an estimate of that "missing" part, i.e., of XIO. In typical case computations of a ring-symmetric CRW [1] we found that the maximum value of XIO was about 0.16., which indicated that as far as interaction with invading ambient molecules is concerned, the approximation MFIN = 34 was a reasonable substitute for MFIN = ∞ .

The next step is the computation by numerical integration of three approximations to the lateral opacity: XI(I,JXI), XIPM(I,JXI), XIGRP(I,JXI). (Note that when the flow is ring-symmetric, the approximation XIPM(I,JXI) obtained by assuming a Prandtl-Meyer flow is usually grossly exaggerated). The opacity XIGRP(I,JXI) is based on the analytic approximation to a ring-symmetric CRW [1], and is reasonably close to XI(I,JXI) which is obtained from the numerical solution to the flow field. Finally, a simplified closed-form integration of lateral opacity [1] is computed as XIAPP(I,JXI) (loop 3). Thus, the quantitative difference between XI(I,JXI) and XIGRP(I,JXI) is an indication to the degree of accuracy achieved by the analytic approximation to a ring-symmetric CRW [1], while the difference between XIGRP(I,JXI) and XIAPP(I,JXI) indicates the level of error introduced by the closed-form integration of lateral opacity [1].

LOADC

Here flow variables of new grid points computed via the SIMA scheme (SEMINV) are loaded into new row arrays from corresponding characteristic arrays.

NUFUNC

This function computes the modified v(M) value as given by Eq. (2.1-2). Note that presently NU0=0 (see INIDAT).

HMSET

This subroutine is called just once from the MAIN PROGRAM. Its task is to set up the arrays in /GRP/, so that the function H(M) [1] can be evaluated by interpolation (in HINTER). There is also an informative printout of various derivatives (see Ch. 3 of [1]) generated in this subroutine.

MFUNC

This subroutine is called by HMSET in order to compute functions of Mach number that serve in the computation of H(M). The output variable F is the integrand for the integration leading to H(M).

HINTER

This subroutine computes H(M) by linear interpolation in inverse Mach number, using the /GRP/arrays computed in HMSET.

MATCH

This subroutine is called from PRINT to compute the Mach number according to the analytic approximation of a ring-symmetric CRW [1], for point (YF,XF(I)). M0B is the associate Mach number $M(0,\beta)$, which is preserved in the array MCHARI(KC) for all CRW characteristics that are used in the SIMA computation. Hence the Mach number $M(\alpha,\beta)$, denoted by MAB can be computed directly from the analytic approximation [1] to the area function at (YF,XF(I)) by calling AREAF. Since typically $M(0,\beta)$ is not known, we also compute the Mach number via the inverse-problem procedure [1], denoting the resulting Mach numbers by suffix I: M0BI for $M(0,\beta)$ and MABI for $M(\alpha,\beta)$. The inverse-problem iterative procedure [1] is performed in loop 1, resulting in M0BI. From M0BI the value of MABI is computed through the area function approximation as for MAB above.

AREAF

This subroutine computes the Mach number M that corresponds to the area function F (Eq. (3.2-1) of [1]). The computation is done by Newton-Raphson iterations, and it has been found to converge when M.GT.1 (and when M-1 is not much smaller than 1).

4. THE JET CODE LISTING

```
C$OPTIONS LIST
                                                                                                                                                                   JET0001
   JET018
                                                                                                                                                                   JET0002
      "JET" - A SEMI-INVERSE MARCHING CHARACTERISTICS METHOD FOR RING JETS. JET0003
USING RIEMANN INVARIANTS RM=(NU+TETA), RP=(NU-TETA) AS FIELD JET0004
                                                                                                                                                                   JET0005
      VARIABLES
             IMPLICIT REAL ×8 (A-H, L-Z, $)
                                                                                                                                                                   JET0006
             REAL *4 XPL, YPL
                                                                                                                                                                   JET0007
             COMMON /PLUME/XPL(1002,10),YPL(1002)
COMMON /IPLUME/KPL,ITYPL(10)
                                                                                                                                                                   JET0008
                                                                                                                                                                   JET0009
             COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
                                                                                                                                                                   JET0010
                                           TETAF(101), BF(101),
                                                                                                                                                                   JET0011
           23
                                          XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                                                                                                   JET0012
                                           TETAN(101), BN(101), XTEMP(101)
                                                                                                                                                                   JET0013
            COMMON/THICKY/XTH(1002),TH(1002)
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20)
                                                                                                                                                                   JET0014
                                                                                                                                                                   JET0015
                                                                                                                                                                   JET0016
             ,XIAPP(101,20),XIF(101,20) JET0017
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0018
             G16,G17,G18,G19,G20
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DYO,DY,DYNEXT,
STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NUO,
TETSYM,TETLIM,DDY,DYMAX
           1
                                                                                                                                                                   JET0019
                                                                                                                                                                   JET0020
           1
                                                                                                                                                                   JET0021
           2
                                                                                                                                                                   JET0022
             COMMON /STAG/RHOO, NO, PO, TO, AO, MDOT1
                                                                                                                                                                   JET0023
             COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                                                                                                   JET0024
             KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD COMMON / ROW/YF, YN, DXF, DXN COMMON / CHARAC/XCHARF(92), YCHARF(92), XCHARN(92), YCHARN(92), YCHARN
                                                                                                                                                                   JET0025
                                                                                                                                                                   JET0026
                                                                                                                                                                   JET0027
                                               RMCARF(92), RPCARF(92), RMCARN(92), RPCARN(92),
                                                                                                                                                                   JET0028
           23
                                               TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
                                                                                                                                                                   JET0029
                                               CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                                                                                                   JET0030
                                               MCHARI(92)
                                                                                                                                                                   JET0031
           4
             COMMON /ICHARA/KCHARP, KCHARM, KCHARO
                                                                                                                                                                   JET0032
             COMMON /GRP/DMINV, MHINV(101), HMV(101)
                                                                                                                                                                   JET0033
             COMMON / IGRP/KHM
                                                                                                                                                                   JET0034
C
                                                                                                                                                                   JET0035
             PRINT 101
                                                                                                                                                                   JET0036
             FORMAT('1')
                                                                                                                                                                   JET0037
  101
              J=1
                                                                                                                                                                    JET0038
             IF(J.EQ.1) STOP
                                                                                                                                                                   JET0039
             CALL INIDAT
PRINT 101
                                                                                                                                                                   JET0040
                                                                                                                                                                   JET0041
             CALL HMSET
                                                                                                                                                                    JET0042
             PRINT 101
                                                                                                                                                                   JET0043
             CALL BEGIN
CALL MARCH
                                                                                                                                                                   JET0044
                                                                                                                                                                   JET0045
             CALL OPACY
                                                                                                                                                                   JET0046
             CALL PLUMES
CALL PRINT
                                                                                                                                                                    JET0047
                                                                                                                                                                   JET0048
              J=2
                                                                                                                                                                   JET0049
                                                                                                                                                                   JET0050
             CALL PLUMES
             CALL MOVE
                                                                                                                                                                   JET0051
             CALL OPACY
                                                                                                                                                                   JET0052
             CALL PRINT
CALL YSTEP
                                                                                                                                                                   JET0053
                                                                                                                                                                   JET0054
              J=J+1
                                                                                                                                                                   JET0055
C
      DY WAS DETERMINED BY THE PREVIOUS CALL TO GRIDN.
                                                                                                                                                                    JET0056
              DY=DMIN1(DYNEXT, DY*DDY, DYMAX)
                                                                                                                                                                   JET0057
      INTEGRATE BY ONE Y-STEP
C
                                                                                                                                                                   JET0058
             CALL MARCH
                                                                                                                                                                   JET0059
       BREAKDOWN PARAMETER (BF(I)).
C
                                                                                                                                                                   JET0060
             CALL BREAK
                                                                                                                                                                   JET0061
       SPECIALLY DESIGNATED LINES (FOR PLOTTING).
C
                                                                                                                                                                   JET0062
              CALL PLUMES
                                                                                                                                                                   JET0063
       STORE NEW LINE (N) IN OLD LINE (F).
C
                                                                                                                                                                   JET0064
      CALL MOVE
COMPUTE RADIAL MOLECULAR OPACITIES
                                                                                                                                                                   JET0065
                                                                                                                                                                   JET0066
             CALL OPACY
                                                                                                                                                                   JET0067
       Y-STEP IS VARIABLE, SO JMAX IS USED AS END-OF-RUN CRITERION.
                                                                                                                                                                   JET0068
C
              IF(YF.GE.YMAX) JMAX=J
                                                                                                                                                                   JET0069
      PRINT FIELD AT MOST RECENT Y.
                                                                                                                                                                   JET0070
             CALL PRINT
                                                                                                                                                                   JET0071
       NEXT Y-STEP.
                                                                                                                                                                   JET0072
```

```
CALL YSTEP
                                                                                      JET0073
       IF(J.LT.JMAX) GO TO 1
                                                                                      JET0074
                                                                                      JET0075
JET0076
       STOP
                                                                    INIDAT
       END
       SUBROUTINE INIDAT
                                                                                      JET0077
   SUBROUTINE NUMBER
                                                                                      JET0078
      IMPLICIT REAL*8(A-H,L-Z,$)
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
                                                                                      JET0079
                                                                                      JET0080
                      TETAF(101), BF(101),
                                                                                      JET0081
                      XN(101), RMN(101), RPN(101), MN(101), MUN(101),
                                                                                      JET0082
                       TETAN(101), BN(101), XTEMP(101)
                                                                                      JET0083
      COMMON/THICKY/XTH(1002),TH(1002)
REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20)
                                                                                      JET0084
                                                                                      JET0085
                                                                                      JET0086
                        ,XIAPP(101,20),XIF(101,20)
                                                                                      JET0087
       COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0088
      G16,G17,G18,G19,G20

COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,
STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,
      1
                                                                                      JET0089
                                                                                      JET0090
                                                                                      JET0091
                     TETSYM, TETLIM, DDY, DYMAX
                                                                                      JET0092
      2
       COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1
                                                                                      JET0093
       COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                      JET0094
                      KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                      JET0095
       COMMON /ROW/YF, YN, DXF, DXN
                                                                                      JET0096
                                                                                      JET0097
C
      PAI=4.D0*DATAN(1.D0)
                                                                                      JET0098
       PAI2=2.D0*DATAN(1.D0)
                                                                                      JET0099
       DEG=180.DO/PAI
                                                                                      JET0100
                                                                                      JET0101
       AR=8.3143D3
       AV=6.022D 26
                                                                                      JET0102
       AW=7.27D0
                                                                                      JET0103
       RH00=0.0075D0
                                                                                      JET0104
                                                                                      JET0105
       T0=2300.D0
       G=1.54D0
                                                                                      JET0106
       D=2.5D-10
                                                                                      JET0107
       MEXIT=4.D0
                                                                                      JET0108
                                                                                      JET0109
       MFIN=34.D0
                                                                                      JET0110
       XC=0.5D0
                                                                                      JET0111
       YC=2.5D0
   DELTA=0 CORRESPONDS TO PLANE SYMMETRY
DELTA=1 CORRESPONDS TO CYLINDRICAL SYMMETRY
                                                                                      JET0112
                                                                                      JET0113
       DELTA=1.D0
                                                                                      JET0114
       FRACG=0.6D0
                                                                                      JET0115
                                                                                      JET0116
       EPSIL=1.D-8
       ITER0=20
                                                                                      JET0117
       KF0=101
                                                                                      JET0118
                                                                                      JET0119
       JMAX=1001
       STAB=0.50D0
                                                                                      JET0120
       DDY=1.05D0
                                                                                      JET0121
       DYMAX=0.5D0
                                                                                      JET0122
                                                                                      JET0123
       YMAX=50.D0
       DY0=YC/250.D0
                                                                                      JET0124
       IDEL=1
                                                                                      JET0125
       JDEL=1
                                                                                      JET0126
   POINTS FOR PRINTING FLOW FIELD AT YF=YXI(JXI)
                                                                                      JET0127
                                                                                      JET0128
       JXI=1
       JYXI=11
                                                                                      JET0129
       DYXI=5.D0
                                                                                      JET0130
       YXI(1)=YC+0.5D0
                                                                                      JET0131
                                                                                      JET0132
       YXI(2)=YXI(1)+2.D0
                                                                                      JET0133
       I0=2
       DO 1 I=I0,JYXI
                                                                                      JET0134
       YXI(I)=YXI(I0)+DYXI*DFLOAT(I-I0)
                                                                                      JET0135
 1
       CONTINUE
                                                                                      JET0136
       IF(KFO.GT.101) CALL FIN(101)
                                                                                      JET0137
       IF(JMAX.GT.1001) CALL FIN(102)
                                                                                      JET0138
       IF(FRACG.GT.1.D0 .OR. FRACG.LT.0.) CALL FIN(103)
                                                                                      JET0139
       IF(JYXI.GT.20) CALL FIN(104)
                                                                                      JET0140
       IF(DELTA*(1.D0-DELTA).NE.0.) CALL FIN(105)
                                                                                      JET0141
                                                                                      JET0142
       NO=RHOO*AV/AW
       A0=DSQRT(G*AR*T0/AW)
                                                                                      JET0143
                                                                                      JET0144
       PO=AR*RHOO*TO/AW
```

```
SIGMA=PAI*D**2
                                                                                          JET0145
       LAMDA0=1.D0/(DSQRT(2.D0)*SIGMA*N0)
                                                                                          JET0146
       G1 = (G-1.D0)/2.D0
                                                                                          JET0147
       G2=(G+1.D0)/(2.D0*(G-1.D0))
                                                                                          JET0148
       G3=G/2.D0
                                                                                          JET0149
       G4=(G+1.D0)/(G-1.D0)
                                                                                          JET0150
       G5=DSQRT((G+1.D0)/(G-1.D0))
                                                                                          JET0151
       G6=1.D0/(G-1.D0)
G7=2.D0/(G+1.D0)
                                                                                          JET0152
                                                                                          JET0153
       G8 = (0.5D0 \times (G+1.D0) \times \times 2/(G-1.D0)) \times \times (1.D0/(G+1.D0)) \times
                                                                                          JET0154
           ((G+1.D0)/(G-1.D0))**((G-1.D0)/(G+1.D0))
                                                                                          JET0155
       G9=(G+3.D0)/(2.D0*(G-1.D0))
G10=(7.D0-3.D0*G)/(2.D0*(G-1.D0))
                                                                                          JET0156
                                                                                          JET0157
       G11=(2.D0/(G+1.D0))**(1.D0/(G-1.D0))
                                                                                          JET0158
       G12=DSQRT((G+1.D0)/(G-1.D0))-1.D0
                                                                                          JET0159
       G13=(2.D0-G)/(2.D0*(G-1.D0))
                                                                                          JET0160
       G14=G/(2.D0×(G-1.D0))
                                                                                          JET0161
       G15=(G+1.D0)/(3.D0-G)
                                                                                          JET0162
       G16=(G+1.D0)/4.D0
                                                                                          JET0163
       G20=LAMDA0*DSQRT(PAI*G/8.D0)
                                                                                          JET0164
       ZETA1=G5*DATAN(DSQRT(MEXIT**2-1.D0)/G5)
                                                                                          JET0165
       AMU1=DARSIN(1.DO/MEXIT)
                                                                                          JET0166
       PSI1=PAI2+AMU1
                                                                                          JET0167
       ZETAF=G5*DATAN(DSQRT(MFIN**2-1.D0)/G5)
                                                                                          JET0168
       PSIF=PSI1+ZETA1-ZETAF
                                                                                          JET0169
       NU0=0.
                                                                                          JET0170
       TETLIM=NUFUNC(MEXIT)+PAI2-NUO
                                                                                          JET0171
       PSILIM=TETLIM
                                                                                          JET0172
       TETSYM=PAI-2.D0*TETLIM
                                                                                          JET0173
       GOREM=1.D0+G1*MEXIT**2
                                                                                          JET0174
       RH01=RH00/GOREM**G6
                                                                                          JET0175
       V1=MEXIT*A0/DSQRT(GOREM)
                                                                                          JET0176
       P1=P0/GOREM**(G/(G-1.D0))
                                                                                          JET0177
       T1=T0/DSQRT(GOREM)
                                                                                          JET0178
       YYC=2.D0*PAI*YC
                                                                                          JET0179
       IF(DELTA.EQ.O.) YYC=1.D0
                                                                                          JET0180
       MDOT1=YYC*XC*RH01*V1
                                                                                          JET0181
C
                                                                                          JET0182
       PRINT 21, AR, AV, AW, G, RHOO, NO, PO, TO, AO, D
                                                                                          JET0183
       FORMAT(/1X, 'THERMODYNAMIC DATA: '/
1X, 'AR, AV, AW, G=', 2X, 2D14.5, 2F9.3/
 21
                                                                                          JET0184
                                                                                          JET0185
                 1X, 'RHOO, NO, PO, TO, AO, D=',6D13.5)
                                                                                          JET0186
       PRINT 22,XC,YC,MEXIT,RHO1,P1,T1,V1,MDOT1,PSI1*DEG,PSIF*DEG,
                                                                                          JET0187
                  PSILIM*DEG
                                                                                          JET0188
      1
 22
       FORMAT(/1X, CORNER DATA: XC, YC=1, 2F9.2/
                                                                                          JET0189
                 1X, 'EXIT CONDITIONS: ',
                                                                                          JET0190
                 2X, 'MEXIT, RHO1, P1, T1, V1, MDOT1=', F9.3, 5D13.4/
1X, 'CENTERED FAN LIMITS:',
      ž
                                                                                          JET0191
      3
                                                                                          JET0192
                 2X, 'PSII, PSIF, PSILIM=', 3F10.3)
                                                                                          JET0193
       PRINT 23,DELTA,KFO,JMAX,ITERO,DYO,YMAX,STAB,DDY
FORMAT(/1X,'INTEGRATION DATA. SYMMETRY INDEX: DELTA=',F4.1/
1X,'NUMBER OF POINTS IN X AND Y DIRECTIONS: KFO,JMAX=',
                                                                                          JET0194
                                                   SYMMETRY INDEX: DELTA=",F4.1/
                                                                                          JET0195
 23
                                                                                          JET0196
      2
                     215/
                                                                                          JET0197
                 1X, 'MAX. NUM. OF ITERATIONS ITERO=', 15/
1X, 'INITIAL Y-STEP AND MAXIMUM Y: DYO, YMAX=', 2D14.5/
1X, 'Y-STEP STABILITY FACTORS STAB, DDY=', 2F7.3)
      3
                                                                                          JET0198
      5
                                                                                          JET0199
                                                                                          JET0200
       RETURN
                                                                                          JET0201
       END
                                                                         REGIN
                                                                                          JET0202
       SUBRUUTINE REGIN
                                                                                          JET0203
   SUBROUTINE NUMBER 2
                                                                                          JET0204
       IMPLICIT REAL *8(A-H,L-Z,$)
                                                                                          JET0205
                                                                                          JET0206
       COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                        TETAF(101), BF(101),
                                                                                          JET0207
                       XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                          JET0208
                        TETAN(101), BN(101), XTEMP(101)
                                                                                          JET0209
       COMMON/THICKY/XTH(1002),TH(1002)

COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0211

G16,G17,G18,G19,G20

JET0212
       COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                          JET0213
                      STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
      1
                                                                                          JET0214
                      TETSYM, TETLIM, DDY, DYMAX
                                                                                          JET0215
       COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1
                                                                                          JET0216
```

```
COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                JET0217
                    KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                JET0218
     COMMON /ROW/YF, YN, DXF, DXN
                                                                                JET0219
     COMMON /CHARAC/XCHARF(92), YCHARF(92), XCHARN(92), YCHARN(92), RMCARF(92), RPCARF(92), RMCARN(92), RPCARN(92),
                                                                                JET0220
                                                                                JET0221
                      TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
    2
                                                                                JET0222
    3
                      CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                JET0223
                      MCHARI(92)
                                                                                JET0224
     COMMON /ICHARA/KCHARP, KCHARM, KCHARO
                                                                                JET0225
                                                                                JET0226
  DEFINE INITIAL CHARACTERISTIC PARAMETERS. USE INTERPOLATION OF
                                                                                JET0227
  RIEMANN INVARIANT ACROSS THE FAN.
                                                                                JET0228
     KCHARP=IDINT(FRACG*DFLOAT(KF0-1)+1.D-6)+1
                                                                                JET0229
     KCHARO=KCHARP+1
                                                                                JET0230
     KCHARM=KCHARO-KCHARP
                                                                                JET0231
     IF(KCHARP.LT.2 ) CALL FIN(200)
                                                                                JET0232
     IF(KCHARO.GT.92) CALL FIN(210)
                                                                                JET0233
     IF(KCHARM.LT. 1) CALL FIN(205)
                                                                                JET0234
     NU1=NUFUNC(MEXIT)
                                                                                JET0235
     RM1=NU0
                                                                                JET0236
     TET1=RM1-NU1
                                                                                JET0237
     RP0=NU1-TET1
                                                                                JET0238
     NUFIN=NUFUNC(MFIN)
                                                                                JET0239
     RPFIN=NUFIN-(RM1-NUFIN)
DRP=(RPFIN-RP0)/DFLOAT(KCHARP-1)
                                                                                JET0240
                                                                                JET0241
     DO 1 KC=1, KCHARP
                                                                                JET0242
     RP1=RP0+DRP*DFLOAT(KC-1)
                                                                                JET0243
     CALL RFUNC(RM1, RP1, M1, MU1, TETA1)
                                                                                JET0244
     MCHARI(KC)=M1
                                                                                JET0245
1
     CONTINUE
                                                                                JET0246
                                                                                JET0247
  DATA FOR C+ CHARACTERISTICS.
  THE RIEMANN INVARIANTS ARE DEFINED IN SUCH A WAY THAT BOTH VANISH AT JET0248
                                                                                JET0249
  INFINITE MACH NUMBER.
                                                                                JET0250
     RM1=NU0
     DO 2 KC=1, KCHARP
                                                                                JET0251
     CSIGNF(KC)=1.D0
                                                                                JET0252
     XCHARF(KC)=XC
YCHARF(KC)=YC
                                                                                JET0253
                                                                                JET0254
     IF(MCHARI(KC).EQ.O.) CALL FIN(231)
                                                                                JET0255
                                                                                JET0256
     NU=NUFUNC(MCHARI(KC))
                                                                                JET0257
JET0258
     TET=RM1-NU
     RP1=NU-TET
     CALL RFUNC(RM1, RP1, M1, MU1, TETA1)
                                                                                JET0259
     MCHARF(KC)=M1
                                                                                JET0260
     MUCARF(KC)=MU1
                                                                                JET0261
     TCHARF(KC)=TETA1
RMCARF(KC)=RM1
                                                                                JET0262
                                                                                JET0263
     RPCARF(KC)=RP1
                                                                                JET0264
                                                                                JET0265
     CONTINUE
  DATA FOR C- CHARACTERISTICS.
                                                                                JET0266
     KC1=KCHARP+1
                                                                                JET0267
                                                                                JET0268
     XCHARF(KC1)=0.8D0*XC
                                                                                JET0269
     DO 21 KC=KC1,KCHARO
     CSIGNF(KC) =-1.D0
                                                                                JET0270
     MCHARI(KC)=MEXIT
                                                                                JET0271
                                                                                JET0272
     MUCARF(KC)=DARSIN(1.DO/MCHARI(KC))
     TCHARF(KC)=PAI2
                                                                                JET0273
     YCHARF(KC)=YC
                                                                                JET0274
     MCHARF(KC)=MEXIT
                                                                                JET0275
                                                                                JET0276
     RMCARF(KC)=RM1
                                                                                JET0277
     RPCARF(KC)=NUFUNC(MEXIT)-(TCHARF(KC)-TETLIM)
                                                                                JET0278
21
     CONTINUE
  DEFINE GRID AND INITIAL CONDITIONS AT EXIT PLANE.
                                                                                JET0279
                                                                                JET0280
     KFAN=KCHARP-1
      ILEAD=KFO-KFAN
                                                                                JET0281
                                                                                JET0282
      KCLEAD=1
      KF=KF0
                                                                                JET0283
      KF2=2×KF
                                                                                JET0284
      YF=YC
                                                                                JET0285
                                                                                JET0286
      DO 3 I=1,KF
      KC=KCLEAD+I-ILEAD
                                                                                JET0287
     IF(KC.GT.KCHARP) CALL FIN(241)
                                                                                JET0288
```

JET0360

PRINT FLOW FIELD AT Y=YF

```
IF(J.EQ.JMAX) JXI=MINO(JXI,JYXI)
                                                                                        JET0361
      IF(J.EQ.1 .OR. J.EQ.JMAX) GO TO 121
IF(JXI.GT.JYXI) GO TO 120
                                                                                       JET0362
                                                                                       JET0363
      IF(YXI(JXI).GT.YF+0.5D0*DY) GO TO 120
                                                                                        JET 0364
121
      CONTINUE
                                                                                        JET0365
      YXI(JXI)=YF
                                                                                       JFT0366
 CALL OPACX
COMPUTE MACH NUMBER FOR CYLINDRICAL EXPANSION MCYL.
                                                                                       JET0367
                                                                                       JET0368
      F=(YF/YC)*(G7*(1.D0+G1*MEXIT**2))**G2/MEXIT
                                                                                       JET0369
     CALL AREAF(F, MCYL)
PRINT 22, JXI, KCLEAD, ILEAD, KF, MCYL, YF
FORMAT(/1X, 'PRINTING NUMBER JXI, KCLEAD, ILEAD, KF=', 414,
5X, 'MCYL, YF=', 2D14.5/)
                                                                                       JET0370
                                                                                       JET0371
                                                                                       JET0372
                                                                                       JET0373
                                                                                       JET0374
                                            XF(I) ','
MF(I) ','
MABI ','
(I(I) ','
                                                           TETAF(I) !,
1
      FORMAT(/1X,' I ',' KC ','
                                                                                       JET0375
                                                                       1,
                                                                                       JET0376
                                                             MAB
    2
                                     9
                                                             MOBI
                                                                                       JET0377
                                     1
                                                            XIGRP(I) 1,
     3
                                           XI(I)
                                                                                       JET0378
                                          XIAPP(I) ','
                                                            XIPM(I)
                                                                       1/)
                                                                                       JET0379
      IDEL1=IDEL
                                                                                       JET0380
      IF(J.EQ.1.OR.J.EQ.JMAX) IDEL1=1
                                                                                       JET0381
      DO 20 I=1,KF,IDEL1
KC=KCLEAD+(I-ILEAD)
                                                                                        JET0382
                                                                                        JET0383
      IF(KC.LT.KCLEAD) KC=0
                                                                                       JET0384
      MOB=1.D10
                                                                                       JET0385
      MOBI=1.D10
                                                                                        JET0386
      MAB=1.D10
                                                                                        JET0387
                                                                                        JET0388
      MABI=1.D10
      MPM=MF(I)
                                                                                        JET0389
      IF(KC.EQ.0) GO TO 23
                                                                                        JET0390
      MOB=MCHARI(KC)
                                                                                        JET0391
      IF(J.EQ.1) GO TO 23
                                                                                        JET0392
      PSIPM=PAI2-DATAN((XF(I)-XC)/(YF-YC))
                                                                                       JET0393
      ZETA=PSI1+ZETA1-PSIPM
                                                                                       JET0394
      MPM=DSQRT((G5*DTAN(ZETA/G5))**2+1.D0)
                                                                                       JET0395
      CALL MATCH(I, MOB, MAB, MOBI, MABI)
                                                                                       JET0396
                                                                                       JET0397
      CONTINUE
      PRINT 21, I, KC, XF(I), TETAF(I) * DEG, MF(I), MAB, MABI, MOBI,
                                                                                       JET0398
                XI(I,JXI),XIGRP(I,JXI),XIAPP(I,JXI),XIPM(I,JXI)
                                                                                       JET0399
21
20
      FORMAT(1X,214,10D12.4)
                                                                                       JET0400
                                                                                        JET0401
      CONTINUE
      IF(J.EQ.1) GO TO 120
                                                                                        JET0402
      IF(J.EQ.JMAX) GO TO 120
                                                                                       JET0403
      JXI=JXI+1
                                                                                        JET0404
120
      CONTINUE
                                                                                        JET0405
      IF(J.LT.JMAX) GO TO 200
                                                                                        JET0406
                                                                                        JET0407
      PRINT 101
      FORMAT('1')
                                                                                       JET0408
101
      PRINT 102
                                                                                        JET0409
      FORMAT(1X, 'RADIAL MOLECULAR THICKNESS J, XTH(J), TH(J)=1/)
PRINT 202, (JJ, XTH(JJ), TH(JJ), JJ=1, JMAX)
                                                                                       JET0410
102
                                                                                       JET0411
      FORMAT(/5(I5,D11.4,D10.3))
                                                                                       JET0412
202
     PRINT 101
PRINT 103, (IPL, ITYPL(IPL), IPL=1, KPL)
FORMAT(1X, 'PLUME TYPES IPL, ITYPL(IPL)=',
2(/1X,5(5X,2I4)))
                                                                                       JET0413
                                                                                       JET0414
                                                                                       JET0415
103
                                                                                       JET0416
      FORMAT(1X, 'PLUME POINTS J, YPL(J), XPL(J,1), XPL(J,2),...='/)
104
                                                                                       JET0418
                                                                                       JET0419
      JDEL1=1
      DO 203 JJ=1,JMAX,JDEL1
PRINT 204,JJ,YPL(JJ),(XPL(JJ,IPL),IPL=1,KPL)
                                                                                       JET0420
                                                                                       JET0421
      FORMAT(1X, 15, 2X, E12.4, 10E11.3)
204
                                                                                       JET0422
203
                                                                                       JET0423
      CONTINUE
 WRITE ON TAPE7 FOR SUBSEQUENT PLOTTING.
NO MORE THAN 80 CHARACTERS PER LINE ON TAPE7.
WRITE(7,205) JMAX,KPL
                                                                                       JET0424
                                                                                       JET0425
                                                                                       JET0426
205
      FORMAT(8I10/8I10)
                                                                                       JET0427
      WRITE(7,205) (ITYPL(IPL),IPL=1,KPL)
                                                                                        JET0428
      DO 210 JJ=1,JMAX
WRITE(7,211) YPL(JJ),(XPL(JJ,IPL),IPL=1,KPL)
                                                                                       JET0429
                                                                                       JET0430
211
      FORMAT(6E13.6/2X,6E13.6/2X,6E13.6/2X,6E13.6)
                                                                                       JET0431
                                                                                        JET0432
210
      CONTINUE
```

END

```
WRITE LATERAL (X) OPACITIES
                                                                                    JET0433
       JXI0=JXI
                                                                                    JET0434
      WRITE(7,205) JXI0,KF0
                                                                                    JET0435
      PRINT 226, JXIO, KFO
                                                                                    JET0436
      FORMAT(///1X, LATERAL (X) OPACITIES JXIO, KF0= 1,218)
 226
                                                                                    JET0437
      DO 220 JXI=1, JXI0
WRITE(7,221) JXI, YXI(JXI)
FORMAT(I10, E13.6)
                                                                                    JET0438
                                                                                    JET0439
                                                                                    JET0440
 221
      PRINT 227, JXI, YXI(JXI)
FORMAT(//1X, 'JXI, YXI(JXI)=', 18, E15.6/)
                                                                                    JET0441
                                                                                    JET0442
 227
                                                                                    JET0443
      DO 225 I=1,KF0
      WRITE(7,211) XIF(I,JXI),XI(I,JXI),XIPM(I,JXI),XIGRP(I,JXI),
XIAPP(I,JXI)
                                                                                    JET0444
                                                                                    JET0445
     1
                   XIF(I,JXI),XI(I,JXI),XIPM(I,JXI),XIGRP(I,JXI),
XIAPP(I,JXI)
                                                                                    JET0446
      PRINT 211,
                                                                                    JET0447
     1
 225
      CONTINUE
                                                                                    JET0448
 220
                                                                                    JET0449
      CONTINUE
 200
      CONTINUE
                                                                                    JET0450
      RETURN
                                                                                    JET0451
                                                                 FIN
                                                                                    JET0452
      END
      SUBROUTINE FIN(IFIN)
                                                                                    JET0453
   SUBROUTINE NUMBER
                                                                                    JET0454
   STOP WHEN ERROR IS DETECTED.

IMPLICIT_REAL*8(A-H,L-Z,$)
                                                                                    JET0455
                                                                                    JET0456
      PRINT 1, IFIN
                                                                                    JET0457
      FORMAT(/1X, 'FIN CODE IFIN=', I6/)
                                                                                    JET0458
   INDUCE ERROR IN ORDER TO GENERATE TRACING OF CALLING SUBROUTINES.
                                                                                    JET0459
      X=-1.D0
                                                                                    JET0460
       Y=X+DSQRT(X)
                                                                                    JET0461
      IF(IFIN.LE.0) GO TO 100
                                                                                    JET0462
      STOP
                                                                                    JET0463
 100
      RETURN
                                                                                    JET0464
                                                                MARCH
                                                                                    JET0465
       END
       SUBROUTINE MARCH
                                                                                    JET0466
   SUBROUTINE NUMBER
                                                                                    JET0467
      IMPLICIT REAL*8(A-H,L-Z,$)
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
                                                                                    JET0468
                                                                                    JET0469
                      TETAF(101), BF(101),
                                                                                    JET0470
                      XN(101), RMN(101), RPN(101), MN(101), MUN(101),
                                                                                    JET0471
                                                                                    JET0472
                      TETAN(101), BN(101), XTEMP(101)
      COMMON/THICKY/XTH(1002), TH(1002)
                                                                                    JET0473
      COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0474
                      G16,G17,G18,G19,G20
                                                                                    JET0475
      COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                    JET0476
                     STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                    JET0477
                     TETSYM, TETLIM, DDY, DYMAX
                                                                                    JET0478
      COMMON /STAG/RHOO, NO, PO, TO, AO, MDOT1
                                                                                    JET0479
      COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,
KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD
                                                                                    JET0480
                                                                                    JET0481
      COMMON /ROW/YF,YN,DXF,DXN
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),
                                                                                    JET0482
                                                                                    JET0483
                        RMCARF(92), RPCARF(92), RMCARN(92), RPCARN(92),
                                                                                    JET0484
                        TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
     23
                                                                                    JET0485
                        CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                    JET0486
                        MCHARI(92)
                                                                                    JET0487
       COMMON /ICHARA/KCHARP, KCHARM, KCHARO
                                                                                    JET0488
                                                                                    JET0489
                                                                                    JET0490
   ADVANCE FLOW FIELD FROM YF TO YN
       IM=KF
                                                                                    JET0491
                                                                                    JET0492
       IP=KF
       YN=YF+DY
                                                                                    JET0493
       KN=KF0
                                                                                    JET0494
C
   SEMI-INVERSE INTEGRATION FOR FAN POINTS.
                                                                                    JET0495
       CALL SEMINV
                                                                                    JET0496
   NEW GRID POINTS (JUST INVERSE MARCHING).
                                                                                    JET0497
C
       CALL GRIDN
                                                                                    JET0498
                                                                                    JET0499
   LOAD FLOW VARIABLES FROM SEMI-INVERSE INTEGRATION INTO VECTORS
C
       CALL LOADC
                                                                                    JET0500
   CHARACTERISTIC SCHEME INTEGRATION FOR INNER POINTS (INVERSE MARCH).
                                                                                    JET0501
       CALL INVMAR
                                                                                    JET0502
       RETURN
                                                                                    JET0503
```

JET0504

```
SUBROUTINE INVMAR
                                                                                    JET0505
   SUBROUTINE NUMBER 6
                                                                                    JET0506
       IMPLICIT REAL *8(A-H, L-Z, $)
                                                                                    JET0507
       COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                                                                                    JET0508
                      TETAF(101), BF(101),
                                                                                    JET0509
      2
3
                      XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                    JET0510
                      TETAN(101), BN(101), XTEMP(101)
                                                                                    JET0511
       COMMON/THICKY/XTH(1002), TH(1002)
                                                                                    JET0512
      COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0513
G16,G17,G18,G19,G20 JET0514
     1
       COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                    JET0515
                     STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                    JET0516
                     TETSYM, TETLIM, DDY, DYMAX
                                                                                    JET0517
      COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1
COMMON /IPAR/JMAX,KFO,ITERO,KF,KN,IM,IP,J,
                                                                                    JET0518
                                                                                    JET0519
                      KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                    JET0520
       COMMON /ROW/YF, YN, DXF, DXN
                                                                                    JET0521
                                                                                    JET0522
   INTEGRATION WITH INVERSE CHARACTERISTICS FOR NEW POINT(X4,Y4).
                                                                                    JET0523
   OLD POINTS ARE (X1,Y1),(X2,Y2).
                                                                                    JET0524
   X1 IS OBTAINED BY INVERSE C- FROM X4
X2 IS OBTAINED BY INVERSE C+ FROM X4
                                                                                    JET0525
                                                                                    JET0526
   NOTE THAT X1 MAY BE NEGATIVE (E. G. WHEN X4=0).
                                                                                    JET0527
       KN1=ILEAD-1
                                                                                    JET0528
       IF(KN1.LE.0) CALL FIN(601)
                                                                                    JET0529
       DO 1000 I=1,KN1
                                                                                    JET0530
       I4=I
                                                                                    JET0531
                                                                                    JET0532
       X4=XN(I)
       Y4=YN
                                                                                    JET0533
       IF4=(IM+IP)/2
                                                                                    JET0534
       CALL INTERP(0, IF4, KF, X4, XF, RM4, RMF, RP4, RPF)
CALL RFUNC(RM4, RP4, M4, MU4, TETA4)
                                                                                    JET0535
                                                                                    JET0536
                                                                                    JET0537
       M14=M4
       MU14=MU4
                                                                                    JET0538
                                                                                    JET0539
       TETA14=TETA4
       M24=M4
                                                                                    JET0540
       MU24=MU4
                                                                                    JET0541
                                                                                    JET0542
       TETA24=TETA4
       Y1=YF
                                                                                    JET0543
                                                                                    JET0544
       Y2=YF
                                                                                    JET0545
       Y14=(Y1+Y4)/2.D0
                                                                                    JET0546
       Y24=(Y2+Y4)/2.D0
       X1=1.D10
                                                                                    JET0547
       X2=1.D10
                                                                                    JET0548
                                                                                    JET0549
       RM4=1.D10
                                                                                    JET0550
       RP4=1.D10
                                                                                    JET0551
       ITER=0
                                                                                    JET0552
       GO TO 2
                                                                                    JET0553
CCC
                                                                                    JET0554
   CORRECTOR
                                                                                    JET0555
                                                                                    JET0556
       ITER=ITER+1
                                                                                    JET0557
C
   AVERAGED PROPERTIES ON C-(14),C+(24) CHARACTERISTICS.
                                                                                    JET0558
       RM14=(RM1+RM4)/2.D0
       RP14=(RP1+RP4)/2.D0
                                                                                    JET0559
                                                                                    JET0560
       RM24=(RM2+RM4)/2.D0
                                                                                    JET0561
       RP24=(RP2+RP4)/2.D0
   M14,MU14,TETA14, M24,MU24.TETA24 AVERAGED ON C-,C+ CHARACTERISTICS.
                                                                                    JET0562
       CALL RFUNC(RM14, RP14, M14, MU14, TETA14)
                                                                                    JET0563
       CALL
            RFUNC(RM24, RP24, M24, MU24, TETA24)
                                                                                    JET0564
                                                                                    JET0565
       CONTINUE
   NEW X1,X2
                                                                                    JET0566
                                                                                    JET0567
       X10=X1
       X20=X2
                                                                                    JET0568
                                                                                    JET0569
       X1=X4-DY/DTAN(TETA14-MU14)
                                                                                    JET0570
       X2=X4-DY/DTAN(TETA24+MU24)
       IF(X2.LT.0.) CALL FIN(670)
                                                                                    JET0571
       D14=DSQRT((X1-X4)**2+DY**2)
                                                                                    JET0572
       D24=DSQRT((X2-X4)**2+DY**2)
                                                                                    JET0573
                                                                                    JET0574
   INTERPOLATE OLD DISTRIBUTION FOR RM1, RP1, RM2, RP2 AT X1, X2.
       CALL INTERP(0,1M,KF,X1,XF,RM1,RMF,RP1,RPF)
CALL INTERP(0,1P,KF,X2,XF,RM2,RMF,RP2,RPF)
                                                                                    JET0575
                                                                                    JET0576
```

```
NO NEED FOR RE-AVERAGING SINCE IT INTRODUCES ONLY HIGHER ORDER
                                                                                       JET0577
  CHANGES INTO THE ITERATION SCHEME
                                                                                       JET0578
  INTEGRATE THE CHARACTERISTIC EQUATIONS FOR RM4, RP4 AT X4, Y4.
                                                                                       JET0579
      RM40=RM4
                                                                                       JET0580
      RP40=RP4
                                                                                       JET0581
      RM4=RM1+DELTA*DSIN(TETA14)*D14/(M14*Y14)
                                                                                       JET0582
                                                                                       JET0583
      RP4=RP2+DELTA*DSIN(TETA24)*D24/(M24*Y24)
  CONVERGENCE TEST
                                                                                       JET0584
      EPS=(DABS(X1-X10)+DABS(X2-X20))/DY+DABS(RM4-RM40)+DABS(RP4-RP40)
IF(ITER.GT.ITER0) GO TO 10
                                                                                        JET0585
                                                                                        JET0586
                                                                                        JET0587
      IF(EPS.GT.EPSIL) GO TO 1
      RMN(I)=RM4
                                                                                        JET0588
      RPN(I)=RP4
                                                                                        JET0589
      CALL RFUNC(RM4, RP4, MN(I), MUN(I), TETAN(I))
                                                                                        JET0590
1000 CONTINUE
                                                                                        JET0591
      RETURN
                                                                                        JET0592
10
      CONTINUE
                                                                                        JET0593
     PRINT 11, I4, KN, IF4, IM, IP, KF, ITER, ITER0, EPS, EPSIL, X1, X2, X4, M14, M24 JET0594 FORMAT(1X, 'SUBR. INVMAR. I4, KN, IF4, IM, IP, KF, ITER, ITER0=', 815/ JET0595 1X, 'EPS, EPSIL, X1, X2, X4, M14, M24=', 7D14.6/) JET0596
11
                                                                                        JET0597
      RETURN
                                                                                        JET0598
                                                                 SEMINV
      END
                                                                                        JET0599
      SUBROUTINE SEMINV
                                                                                        JET0600
  SUBROUTINE NUMBER
                                                                                       JET0601
      IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                        JET0602
      COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                                                                                        JET0603
                      TETAF(101), BF(101),
                                                                                        JET0604
     2
                      XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                        JET0605
                      TETAN(101), BN(101), XTEMP(101)
                                                                                        JET0606
      COMMON/THICKY/XTH(1002), TH(1002)
                                                                                        JET0607
      COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0608
G16,G17,G18,G19,G20 JET0609
      COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                       JET0610
                     STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                        JET0611
                     TETSYM, TETLIM, DDY, DYMAX
                                                                                        JET0612
     2
      COMMON /STAG/RHO0, NO, PO, TO, AO, MDOT1
                                                                                        JET0613
      COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                        JET0614
                      KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                        JET0615
     COMMON /ROW/YF,YN,DXF,DXN
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),
RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),
RMCARF(92),RPCARR(92),RMCARN(92),RPCARN(92),
                                                                                        JET0616
                                                                                        JET0617
                                                                                        JET0618
     2
                        TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
                                                                                       JET0619
                        CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                        JET0620
     4
                        MCHARI(92)
                                                                                        JET0621
      COMMON / ICHARA/KCHARP, KCHARM, KCHARO
                                                                                        JET0622
                                                                                        JET0623
                                                                                        JET0624
  COMPUTE NEW POINT (X4,Y4), BY PASSING A C+ CHARACTERISTIC
  THROUGH OLD POINT (X2, Y2). BOTH POINTS ARE ON CHARACTERISTIC LINE
                                                                                        JET0625
  NUMBER KC.
                                                                                        JET0626
      IM=1
                                                                                        JET0627
      DO 100 KC=1, KCHAR0
                                                                                        JET0628
      IF(CSIGNN(KC).EQ.O.) GO TO 100
                                                                                        JET 0629
                                                                                        JET0630
  PREDICTOR
                                                                                        JET0631
                                                                                        JET0632
      Y1=YF
                                                                                        JET0633
      Y2=YF
                                                                                        JET 0634
      Y4=YN
                                                                                        JET0635
      Y14 = (Y1 + Y4)/2.D0
                                                                                        JET0636
      Y24=(Y2+Y4)/2.D0
                                                                                       JET0637
      X2=XCHARF(KC)
                                                                                        JET0638
      RM2=RMCARF(KC)
                                                                                        JET 0639
                                                                                        JET0640
      RP2=RPCARF(KC)
      M2=MCHARF(KC)
                                                                                        JET0641
      MU2=MUCARF(KC)
                                                                                        JET0642
      TETA2=TCHARF(KC)
                                                                                        JET0643
      M14=M2
                                                                                        JET0644
      MU14=MU2
                                                                                        JET0645
      TETA14=TETA2
                                                                                       JET0646
      M24=M2
                                                                                       JET0647
      MU24=MU2
                                                                                        JET0648
```

```
TETA24=TETA2
                                                                                     JET0649
       X4=1.D10
                                                                                     JET0650
       X1=1.D10
                                                                                     JET0651
       RM4=1.D10
                                                                                     JET0652
       RP4=1.D10
                                                                                     JET0653
       ITER=0
                                                                                     JET0654
       GO TO 2
                                                                                     JET0655
CCC
                                                                                     JET0656
   CORRECTOR
                                                                                     JET0657
                                                                                     JET0658
       ITER=ITER+1
                                                                                     JET0659
C
   AVERAGED PROPERTIES ON C-(14),C+(24) CHARACTERISTICS.
                                                                                     JET0660
       RM14=(RM1+RM4)/2.D0
                                                                                     JET0661
       RP14=(RP1+RP4)/2.D0
                                                                                     JET0662
       RM24=(RM2+RM4)/2.D0
                                                                                     JET0663
   RP24=(RP2+RP4)/2.D0
M14,MU14,TETA14, M24,MU24,TETA24 AVERAGED ON C-,C+ CHARACTERISTICS.
                                                                                     JET0664
                                                                                     JET0665
       CALL RFUNC(RM14, RP14, M14, MU14, TETA14)
                                                                                     JET0666
       CALL RFUNC(RM24, RP24, M24, MU24, TETA24)
                                                                                     JET0667
       CONTINUE
                                                                                     JET0668
   NEW X4,X1
                                                                                     JET0669
       X40=X4
                                                                                     JET0670
       X10=X1
                                                                                     JET0671
       X4=X2+DY/DTAN(TETA24+CSIGNF(KC)*MU24)
                                                                                     JET0672
       X1=X4-DY/DTAN(TETA14-CSIGNF(KC)*MU14)
                                                                                     JET0673
       D14=DSQRT((X1-X4)**2+DY**2)
                                                                                     JET0674
       D24=DSQRT((X2-X4)**2+DY**2)
                                                                                     JET0675
   INTERPOLATE OLD DISTRIBUTION FOR RM1, RP1, AT X1.
                                                                                     JET0676
       CALL INTERP(0, IM, KF, X1, XF, RM1, RMF, RP1, RPF)
                                                                                     JET0677
       IF(J.GT.1) GO TO 22
IF(CSIGNF(KC).LT.0.) GO TO 22
                                                                                     JET0678
                                                                                     JET0679
       RP1=RP2
                                                                                     JET0680
 22
       CONTINUE
                                                                                     JET0681
   NO NEED FOR RE-AVERAGING SINCE IT INTRODUCES ONLY HIGHER ORDER CHANGES INTO THE ITERATION SCHEME.
                                                                                     JET0682
                                                                                     JET0683
   INTEGRATE THE CHARACTERISTIC EQUATIONS FOR RM4, RP4 AT X4, Y4.
                                                                                     JET0684
       RM40=RM4
                                                                                     JET0685
       RP40=RP4
                                                                                     JET0686
       IF(CSIGNF(KC).LT.0.) GO TO 21
RM4=RM1+DELTA*DSIN(TETA14)*D14/(M14*Y14)
                                                                                     JET0687
       RP4=RP2+DELTA*DSIN(TETA24)*D24/(M24*Y24)
GO TO 20
                                                                                     JET0688
                                                                                     JET0689
       GO TO 20
                                                                                     JET0690
       CONTINUE
                                                                                     JET0691
 21
       RM4=RM2+DELTA*DSIN(TETA24)*D24/(M24*Y24)
                                                                                     JET0692
       RP4=RP1+DELTA*DSIN(TETA14)*D14/(M14*Y14)
                                                                                     JET0693
       CONTINUE
 20
                                                                                     JET0694
   CONVERGENCE TEST
                                                                                     JET0695
        EPS = (DABS(X4-X40)+DABS(X1-X10))/DY+DABS(RM4-RM40)+DABS(RP4-RP40) 
                                                                                     JET0696
       IF(ITER.GT.ITER0) GO TO 10
                                                                                     JET0697
       IF(EPS.GT.EPSIL) GO TO 1
                                                                                     JET0698
       CSIGNN(KC)=CSIGNF(KC)
                                                                                     JET0699
       IF(X4.GT.0.) GO TO 30
                                                                                     JET0700
       RMSAVE=RM4
                                                                                     JET0701
       RM4=RP4+TETSYM
                                                                                     JET0702
       RP4=RM4-TETSYM
                                                                                     JET0703
       CSIGNN(KC)=-1.D0
                                                                                     JET0704
                                                                                     JET0705
 30
       CONTINUE
       RMCARN(KC)=RM4
                                                                                     JET0706
       RPCARN(KC)=RP4
                                                                                     JET0707
       CALL RFUNC(RM4, RP4, M4, MU4, TETA4)
                                                                                     JET0708
       TCHARN(KC)=TETA4
                                                                                     JET0709
       XCHARN(KC)=DABS(X4)
YCHARN(KC)=Y4
                                                                                     JET0710
                                                                                     JET0711
       MUCARN(KC)=MU4
                                                                                     JET0712
       MCHARN(KC)=M4
                                                                                     JET0713
 100
       CONTINUE
                                                                                     JET0714
       RETURN
                                                                                     JET0715
       CONTINUE
                                                                                     JET0716
 10
       PRINT 11,KC,KCHARO,IM,KF,ITER,ITERO,EPS,EPSIL,X1,X2,X4,M14,M24
FORMAT(1X,'SUBR. SEMINV. KC,KCHARO,IM,KF,ITER,ITERO=',615/
1X,'EPS,EPSIL,X1,X2,X4,M14,M24=',7D14.6/)
                                                                                     JET0717
                                                                                     JET0718
 11
                                                                                     JET0719
       CALL FIN(711)
                                                                                     JET0720
```

```
RETURN
                                                                                                 JET0721
                                                                               RFUNC
           SUBROUTINE RFUNC(RM, RP, M, MU, TETA)
                                                                                                 JFT.0722
                                                                                                 JET0723
       SUBROUTINE NUMBER 8
IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                                 JET0724
                                                                                                 JET0725
           COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                                                                                                 JET0726
                            TETAF(101), BF(101),
                                                                                                 JET0727
                            XN(101), RMN(101), RPN(101), MN(101), MUN(101),
          2
                                                                                                 JET0728
          3
                            TETAN(101), BN(101), XTEMP(101)
                                                                                                 JET0729
           COMMON/THICKY/XTH(1002),TH(1002)
                                                                                                 JET0730
           COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0731
           G16,G17,G18,G19,G20

COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,
STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,
                                                                                                 JET0732
                                                                                                 JET0733
                                                                                                 JET0734
                           TETSYM, TETLIM, DDY, DYMAX
                                                                                                 JET0735
          2
           COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1
COMMON /IPAR/JMAX,KFO,ITERO,KF,KN,IM,IP,J,
                                                                                                 JET0736
                                                                                                 JET0737
                            KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                                 JET0738
           COMMON /ROW/YF, YN, DXF, DXN
                                                                                                 JET0739
                                                                                                 JET0740
       COMPUTE M, MU, TETA AT A POINT, AS FUNCTION OF RIEMANN INVAR. RM, RP.
                                                                                                 JET0741
           TETA=(RM-RP)/2.D0+TETLIM
                                                                                                 JET0742
               =(RM+RP)/2.D0
                                                                                                 JET0743
       NU=NUO-(G5*ARCTAN(G5*Q)-ARCTAN(Q)), WHERE Q=(M**2-1)**(-1/2)
                                                                                                 JET0744
       FIND Q(NU), AND HENCE M(NU), THROUGH NEWTON RAPHSON ITERATIONS. Q=-(NU-NU0)/(G4-1.D0)
                                                                                                 JET0745
JET0746
           IF(Q.LE.O.) CALL FIN(801)
                                                                                                 JET0747
                                                                                                 JET0748
            ITER=0
     1
           ITER=ITER+1
                                                                                                 JET0749
           QF=Q
                                                                                                 JET0750
           DNUDT=-(G4-1.D0)/((1.D0+G4*Q**2)*(1.D0+Q**2))
                                                                                                 JET0751
           DNU=NU-(NUO-(G5*DATAN(G5*Q)-DATAN(Q)))
                                                                                                 JET0752
           Q=Q+DNU/DNUDT
                                                                                                 JET0753
           IF(Q.LE.O.) CALL FIN(811)
EPS=DABS(Q-QF)/Q
IF(ITER.GT.ITERO) GO TO 10
                                                                                                 JET0754
JET0755
                                                                                                 JET0756
            IF(EPS.GT.EPSIL*1.D-3) GO TO 1
                                                                                                 JET0757
           M=DSQRT(1.D0+1.D0/Q**2)
                                                                                                 JET0758
           MU=DARSIN(1.D0/M)
                                                                                                 JET0759
           RETURN
                                                                                                 JET0760
     10
           CONTINUE
                                                                                                 JET0761
           CALL FIN(810)
                                                                                                 JET0762
           RETURN
                                                                                                 JET0763
                                                                           INTERP
                                                                                                 JET0764
           END
            SUBROUTINE INTERP(JNEW, I, KGRID, X, XVEC, RM, RMVEC, RP, RPVEC)
                                                                                                 JET0765
       SUBROUTINE NUMBER
   C
                                                                                                 JET0766
           IMPLICIT REAL*8(A-H,L-Z,$)
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
                                                                                                 JET0767
                                                                                                 JET0768
                            TETAF(101), BF(101),
                                                                                                 JET0769
                            XN(101), RMN(101), RPN(101), MN(101), MUN(101),
                                                                                                 JET0770
                            TETAN(101), BN(101), XTEMP(101)
                                                                                                 JET0771
           COMMON/THICKY/XTH(1002), TH(1002)
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0773
           G16,G17,G18,G19,G20
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DYO,DY,DYNEXT,
          1
                                                                                                 JET0774
                                                                                                 JET0775
                           STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
          1
                                                                                                 JET0776
                           TETSYM, TETLIM, DDY, DYMAX
          2
                                                                                                 JET0777
           COMMON /STAG/RHO0,N0,P0,T0,A0,MDOT1
                                                                                                 JET0778
           COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                                 JET0779
           KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD COMMON / ROW/YF, YN, DXF, DXN DIMENSION XVEC(1), RMVEC(1), RPVEC(1)
                                                                                                 JET0780
                                                                                                 JET0781
                                                                                                 JET0782
                                                                                                 JET0783
       FIND I SUCH THAT XVEC(I).LE.X.AND.XVEC(I+1).GE.X
FIND RM,RP BY LINEAR INTERPOLATION.
NOTE THAT X MAY BE NEGATIVE.
IF(DABS(X).LE.XVEC(KGRID)) GO TO 901
                                                                                                 JET0784
                                                                                                 JET0785
                                                                                                 JET0786
                                                                                                 JET0787
PRINT 900, X, KGRID, XVEC(KGRID) FORMAT(/1X, D15.7, I10, 4X, D15.7/)
                                                                                                 JET0788
                                                                                      JET0789
           CALL FIN(900)
                                                                                                 JET0790
     901
           CONTINUE
                                                                                                 JET0791
           KG2=2*KGRID
                                                                                                 JET0792
```

```
IO=MINO(I,KGRID-2)
                                                                                 JET0793
     ICOUNT=0
                                                                                 JET0794
1
     I = I0
                                                                                 JET0795
     SIGN1=1.D0
                                                                                 JET0796
     IF(I.GE.1) GO TO 10
                                                                                 JET0797
     SIGN1=-1.D0
                                                                                 JET0798
     I = -I + 2
                                                                                 JET0799
10
     CONTINUE
                                                                                 JET0800
     IF(I.GT.KGRID) CALL FIN(901)
                                                                                 JET0801
     XX1=SIGN1*XVEC(I)
                                                                                 JET0802
     I1=I
                                                                                 JET0803
     IF(XX1.LE.X) GO TO 11
                                                                                 JET0804
     I0=I0-1
                                                                                 JET0805
     ICOUNT=ICOUNT+1
                                                                                 JET0806
                                                                                 JET0807
     IF(ICOUNT.GT.KG2) CALL FIN(911)
     GO TO 1
                                                                                 JET0808
11
     CONTINUE
                                                                                 JET0809
     I = I0 + 1
                                                                                 JET0810
     SIGN2=1.D0
                                                                                 JET0811
     IF(I.GE.1) GO TO 12
                                                                                 JET0812
     SIGN2=-1.DO
                                                                                 JET0813
     I = -I + 2
                                                                                 JET0814
12
     CONTINUE
                                                                                 JET0815
     IF(I.GT.KGRID) CALL FIN(912)
                                                                                 JET0816
     XX2=SIGN2*XVEC(I)
                                                                                 JET0817
     I2=I
                                                                                 JET0818
     IF(XX2.GE.X) GO TO 13
                                                                                 JET0819
     IO=I0+1
                                                                                 JET0820
     ICOUNT=ICOUNT+1
                                                                                 JET0821
     IF(ICOUNT.GT.KG2) CALL FIN(913)
                                                                                 JET0822
     GO TO 1
                                                                                 JET0823
13
     CONTINUE
                                                                                 JET0824
     F1=(XX2-X)/(XX2-XX1)
                                                                                 JET0825
                                                                                 JET0826
     F2=1.D0-F1
     IF(F1.LT.0.) CALL FIN(991)
IF(F2.LT.0.) CALL FIN(992)
                                                                                 JET0827
                                                                                 JET0828
     RM1=RMF(I1)
                                                                                 JET0829
     RP1=RPF(II)
                                                                                 JET0830
     RM2=RMF(I2)
                                                                                 JET0831
     RP2=RPF(I2)
                                                                                 JET0832
     IF(SIGN1.LT.0.) RM1=RPF(I1)+TETSYM
IF(SIGN1.LT.0.) RP1=RMF(I1)-TETSYM
                                                                                 JET0833
                                                                                 JET0834
     IF(SIGN2.LT.0.) RM2=RPF(I2)+TETSYM
                                                                                 JET0835
     IF(SIGN2.LT.0.) RP2=RMF(I2)-TETSYM
                                                                                 JET0836
     RM=F1×RM1+F2×RM2
                                                                                 JET0837
     RP=F1*RP1+F2*RP2
                                                                                 JET0838
     RETURN
                                                                                 JET0839
                                                              INTERX
                                                                                 JET0840
     END
     SUBROUTINE INTERX(JNEW, II, VARO, VAR, KGRID, XO, XVEC)
                                                                                 JET0841
  SUBROUTINE NUMBER 10
IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                 JET0842
                                                                                 JET0843
     COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                                                                                 JET0844
                    TETAF(101), BF(101),
                                                                                 JET0845
                    XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                 JET0846
                    TETAN(101), BN(101), XTEMP(101)
                                                                                 JET0847
     COMMON/THICKY/XTH(1002),TH(1002)
                                                                                 JET0848
     COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0849
    1
                    G16,G17,G18,G19,G20
                                                                                JET0850
     COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                 JET0851
                   STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                 JET0852
    2
                   TETSYM, TETLIM, DDY, DYMAX
                                                                                 JET0853
     COMMON /STAG/RHOO, NO, PO, TO, AO, MDOT1
                                                                                 JET0854
     COMMON / IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                 JET0855
     KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
COMMON / ROW/YF, YN, DXF, DXN
    1
                                                                                 JET0856
                                                                                 JET0857
     DIMENSION VAR(1), XVEC(1)
                                                                                 JET0858
  FIND XO AND I1 SUCH THAT XVEC(I1) < XO < XVEC(I1+1), AND XO CORRESPONDS
                                                                                 JET0859
  TO THE LOCATION AT WHICH VARO IS A LINEAR INTERPOLATION OF VAR(I).
                                                                                 JET0860
     X0=1.D23
                                                                                 JET0861
     IFIRST=I1
                                                                                 JET0862
     IF(I1.GT.0) GO TO 10
                                                                                 JET0863
     IFIRST=KGRID-IABS(I1)+2
                                                                                 JET0864
```

```
10
      CONTINUE
                                                                                          JET0865
      DO 1 II=IFIRST, KGRID
                                                                                          JET0866
      I=II
                                                                                          JET0867
      IF(I1.GT.0) GO TO 11
                                                                                          JET0868
      I=KGRID-II+2
                                                                                          JET0869
11
      CONTINUE
                                                                                          JET0870
      IF(I.LE.0) CALL FIN(1001)
IF(I.GT.KGRID) CALL FIN(1002)
                                                                                          JET0871
                                                                                          JET0872
      IF(I.EQ.1) GO TO 1
                                                                                          JET0873
      IF((VAR(I)-VARO)*(VAR(I-1)-VARO).GT.0.) GO TO 1
IF(VAR(I).EQ.VAR(I-1)) GO TO 1
F1=(VAR(I)-VARO)/(VAR(I)-VAR(I-1))
                                                                                          JET0874
                                                                                          JET0875
                                                                                          JET 0876
      F2=1.D0-F1
                                                                                          JET0877
      IF(F1.LT.0.) CALL FIN(1011)
IF(F2.LT.0.) CALL FIN(1012)
                                                                                          JET0878
                                                                                          JET0879
      X0=F1*XVEC(I-1)+F2*XVEC(I)
                                                                                          JET0880
      I1=I-1
                                                                                          JET0881
      GO TO 2
                                                                                          JET0882
1 2
      CONTINUE
                                                                                          JET0883
                                                                                          JET0884
      CONTINUE
                                                                                          JET0885
      RETURN
                                                                       RREAK
      END
                                                                                          JET0886
      SUBROUTINE BREAK
                                                                                          JET0887
  SUBROUTINE NUMBER 11
IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                          JET0888
                                                                                          JET0889
      REAL MB, MX, MY
                                                                                          JET0890
      COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                                                                                          JET0891
     1
                      TETAF(101), BF(101),
                                                                                          JET0892
                      XN(101), RMN(101), RPN(101), MN(101), MUN(101),
                                                                                          JET0893
                                                                                          JET0894
                       TETAN(101), BN(101), XTEMP(101)
      COMMON/THICKY/XTH(1002),TH(1002)
                                                                                          JET0895
      COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0896
      G16,G17,G18,G19,G20

COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,

STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,
                                                                                          JET0897
                                                                                          JET0898
                                                                                          JET0899
     1
                     TETSYM, TETLIM, DDY, DYMAX
     2
                                                                                          JET0900
      COMMON /STAG/RHO0,N0,P0,T0,A0,MDOT1
                                                                                          JET0901
      COMMON / IPAR/JMAX, KF0, ITER0, KF, KN, IM, IP, J,
                                                                                          JET 0902
                                                                                          JET0903
                      KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
      COMMON /ROW/YF,YN,DXF,DXN
                                                                                          JET0904
                                                                                          JET0905
  COMPUTE THE BREAKDOWN PARAMETER AT (I-1/2,K-1/2). STORE IN BN(I). YB=0.5D0*(YF+YN)
                                                                                          JET0906
                                                                                          JET0907
      DYY=DY
                                                                                          JET0908
      IM=2
                                                                                          JET0909
      DO 1
                                                                                          JET0910
JET0911
            I=2,KN
      X1=XN(I-1)
      X2=XN(I)
                                                                                          JET0912
      DXX=X2-X1
                                                                                          JET0913
      IF(X2.GT.XF(KF)) GO TO 2
CALL INTERP(0,IM,KF,X1,XF,RM1,RMF,RP1,RPF)
CALL INTERP(0,IM,KF,X2,XF,RM2,RMF,RP2,RPF)
                                                                                          JET0914
                                                                                          JET0915
                                                                                          JET0916
      CALL RFUNC(RM1, RP1, M1, MU1, TETA1)
                                                                                          JET0917
      CALL RFUNC(RM2, RP2, M2, MU2, TETA2)
                                                                                          JET0918
      MX=0.5D0*((MN(I)-MN(I-1))+(M2-M1))/DXX
MY=0.5D0*((MN(I)-M2)+(MN(I-1)-M1))/DYY
                                                                                          JET0919
                                                                                          JET0920
      MB=0.25D0*(MN(I-1)+MN(I)+M1+M2)
                                                                                          JET0921
      TETAB=0.25D0*(TETAN(I-1)+TETAN(I)+TETA1+TETA2)
                                                                                          JET0922
      GOREM=MB**2*(1.D0+G1*MB**2)**(G6-1.D0)
                                                                                          JET0923
      GRAD=MX*DCOS(TETAB)+MY*DSIN(TETAB)
                                                                                          JET0924
      B=G20*GOREM*GRAD
                                                                                          JET0925
      GO TO 3
                                                                                          JET0926
2
                                                                                          JET0927
      B=1.D22
      BN(I)=B
                                                                                          JET0928
                                                                                          JET0929
      CONTINUE
      BN(1)=BN(2)
                                                                                          JET0930
                                                                  OPACY
      RETURN
                                                                                          JET0931
      END
                                                                                          JET0932
      SUBROUTINE OPACY
                                                                                          JET0933
  SUBROUTINE NUMBER 12
                                                                                          JET0934
      IMPLICIT REAL *8 (A-H, L-Z, $)
                                                                                          JET0935
```

COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),

```
TETAF(101), BF(101)
                                                                                       JET0937
      123
                       XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                       JET0938
                       TETAN(101), BN(101), XTEMP(101)
                                                                                       JET0939
       COMMON/THICKY/XTH(1002),TH(1002)
                                                                                       JET0940
       COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0941
                       G16,G17,G18,G19,G20
                                                                                       JET0942
       COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                       JET0943
                      STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                       JET0944
      ž
                      TETSYM, TETLIM, DDY, DYMAX
                                                                                       JET0945
       COMMON /STAG/RHO0,N0,P0,T0,A0,MDOT1
                                                                                       JET0946
       COMMON / IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                       JFT0947
                       KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                       JET0948
       COMMON /ROW/YF, YN, DXF, DXN
                                                                                       JET0949
                                                                                       JET0950
    COMPUTE THE MOLECULAR THICKNESS AT END POINTS OF EACH ROW.
                                                                                       JET0951
       IM=2
                                                                                       JET0952
       XTH(J)=XF(KF)
                                                                                       JET0953
       TH(J)=0.
                                                                                       JET0954
       DTH0=N0*SIGMA*DY
                                                                                       JET0955
       IF(J.EQ.1) GO TO 11
                                                                                       JET0956
       J1=J-1
                                                                                       JET0957
       DO 1 JJ=1,J1
XX1=XTH(JJ)
                                                                                       JET0958
                                                                                       JET0959
       CALL INTERP(0, IM, KF, XX1, XF, RM1, RMF, RP1, RPF)
                                                                                       JET0960
       CALL RFUNC(RM1, RP1, M1, MU1, TETA1)
                                                                                       JET0961
       GOREM=1.D0+G1*M1**2
                                                                                       JET0962
       DTH=DTH0/GOREM××G6
                                                                                       JET0963
       TH(JJ) = TH(JJ) + DTH
                                                                                       JET0964
       CONTINUE
                                                                                       JET0965
 īı
       CONTINUE
                                                                                       JET0966
                                                                PLUMES
       RETURN
                                                                                       JET0967
                                                                                       JET0968
       SUBROUTINE PLUMES
                                                                                       JET0969
    SUBROUTINE NUMBER 13
                                                                                       JET0970
       IMPLICIT REAL ×8(A-H, L-Z, $)
                                                                                       JET0971
       REAL*4 XPL, YPL
                                                                                       JET0972
       COMMON /PLUME/XPL(1002,10), YPL(1002)
                                                                                       JET0973
                                                                                       JET0974
       COMMON /IPLUME/KPL, ITYPL(10)
       DIMENSION VPL(92)
                                                                                       JET0975
       COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                                                                                       JET0976
                       TETAF(101), BF(101),
                                                                                       JET0977
                       XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                       JET0978
                       TETAN(101), BN(101), XTEMP(101)
                                                                                       JET0979
       COMMON/THICKY/XTH(1002),TH(1002)
                                                                                       JET0980
       REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF
                                                                                       JET0981
       COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20),XIAPP(101,20),XIF(101,20)
                                                                                       JET0982
      1
                                                                                       JET0983
       COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET0984
      1
                       G16,G17,G18,G19,G20
                                                                                       JET0985
       COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT, STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                       JET0986
                                                                                       JET0987
                      TETSYM, TETLIM, DDY, DYMAX
                                                                                       JET0988
       COMMON /STAG/RHO0, NO, PO, TO, AO, MDOT1
                                                                                       JET0989
       COMMON / IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                       JET0990
       KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD COMMON / ROW/YF, YN, DXF, DXN
                                                                                       JET0991
                                                                                       JET0992
       COMMON /CHARAC/XCHARF(92), YCHARF(92), XCHARN(92), YCHARN(92), RMCARF(92), RPCARF(92), RMCARN(92), RPCARN(92),
                                                                                       JET0993
                                                                                       JET0994
      23
                         TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
                                                                                       JET0995
                         CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                       JET0996
                         MCHARI(92)
                                                                                       JET0997
       COMMON /ICHARA/KCHARP, KCHARM, KCHARO
                                                                                       JET0998
0000000000
   COMPUTE SPECIAL POINTS AT Y=YN, AND STORE THEM AS
                                                                                       JET0999
   (XPL(J, IPL), YPL(J)=YN).

J IS THE MARCHING INDEX OF YN.

IPL=1,2,..., KPL IS THE "PLUME" INDEX.
                                                                                       JET1000
                                                                                       JET1001
                                                                KPL.LE.5
                                                                                       JET1002
                                                  PRESENTLY
   VPL(IPL) IS A VALUE DEFINING THE "PLUME" CURVE.
                                                                                       JET1003
    ITYPL(IPL) IS
                    THE TYPE OF CURVE. IT DEFINES CURVES AS FOLLOWS:
                                                                                       JET1004
    ITYPL(IPL)=0
                    DO NOTHING
                                                                                       JET1005
    ITYPL(IPL)=1
                    REAL PLUME. IT IS THE BREAKDOWN SURFACE, DEFINED BY A CONSTANT VALUE OF THE BREAKDOWN PARAMETER B.
                                                                                       JET1006
                                                                                       JET1007
```

VPL(IPL)=B.

SET

```
CONSTANT MACH-NUMBER LINE. VPL(IPL)=M.

A SINGLE STREAMLINE. VPL(IPL) IS SET TO THE EXIT

X-COORDINATE OF THAT STREAMLINE.

A SINGLE C+ CHARACTERISTIC LINE STARTING AT THE CORNER.JET1012

VPL(IPL) IS SET TO THE INDEX KC OF THAT CHARACTERISTIC JET1013
    ITYPL(IPL)=2
000000000
    ITYPL(IPL)=3
    ITYPL(IPL)=4
                                                                                                JET1014
                      LINE.
    ITYPL(IPL)=5
                      A CONSTANT LATERAL (X) OPACITY LINE.
                                                                       VPL(IPL) IS SET
                                                                                                JET1015
                      TO THE VALUE OF THE (CONSTANT) OPACITY.
                                                                                                JET1016
                                                                                                JET1017
    DEFINE ITYPL(IPL) AND VPL(IPL)
                                                                                                JET1018
        KPL=10
                                                                                                JET1019
        IF(KPL.GT.10) CALL FIN(1301)
                                                                                                JET1020
        DO 2000 IPL=1,KPL
GO TO (2001,2002,2003,2004,2005,2006,2007,2008,2009,2010),IPL
                                                                                                JET1021
                                                                                                JET1022
        ITYPL(IPL)=4
2001
                                                                                                JET1023
        VPL(IPL)=1
                                                                                                JET1024
       GO TO 2000
ITYPL(IPL)=4
                                                                                                JET1025
                                                                                                JET1026
2002
        VPL(IPL)=KCHARP
                                                                                                JET1027
        GO TO 2000
                                                                                                JET1028
2003
        ITYPL(IPL)=4
                                                                                                JET1029
        VPL(IPL)=19
                                                                                                JET1030
        GO TO 2000
ITYPL(IPL)=4
                                                                                                JET1031
2004
                                                                                                JET1032
        VPL(IPL)=31
                                                                                                JET1033
       GO TO 2000
ITYPL(IPL)=4
                                                                                                JET1034
2005
                                                                                                JET1035
        VPL(IPL)=47
                                                                                                JET1036
        GO TO 2000
                                                                                                JET1037
        ITYPL(IPL)=4
2006
                                                                                                JET1038
        VPL(IPL)=55
                                                                                                JET1039
        GO TO 2000
                                                                                                JET1040
        ITYPL(IPL)=1
                                                                                                JET1041
2007
        VPL(IPL)=0.02D0
                                                                                                JET1042
       GO TO 2000
ITYPL(IPL)=1
                                                                                                JET1043
2008
                                                                                                JET1044
        VPL(IPL)=0.03D0
                                                                                                JET1045
        GO TO 2000
                                                                                                JET1046
        ITYPL(IPL)=1
2009
                                                                                                JET1047
        VPL(IPL)=0.05D0
                                                                                                JET1048
        GO TO 2000
                                                                                                JET1049
        ITYPL(IPL)=1
                                                                                                JET1050
2010
        VPL(IPL)=0.08D0
                                                                                                JET1051
        GO TO 2000
                                                                                                JET1052
 2000 CONTINUE
                                                                                                JET1053
   COMPUTE "PLUME" POINTS AT Y=YN
                                                                                                JET1054
        DO 1000 IPL=1,KPL
                                                                                                JET1055
        ITYP=ITYPL(IPL)
                                                                                                JET1056
        IF(ITYP.EQ.0) GO TO 1000
GO TO (1,2,3,4,5), ITYP
                                                                                                JET1057
                                                                                                JET1058
        CONTINUE
                                                                                                JET1059
    BREAKDOWN SURFACE PLUME.
NOTE THAT DUE TO DIFFERENCE-CENTERING OF GRADIENTS, THE ACCURATE Y-COORDINATE IS 0.5*(YF+YN), RATHER THAN YN. IT CAN BE ADJUSTED IN THE PLOTTING CODE.
                                                                                                JET1060
                                                                                                JET1061
                                                                                                JET1062
                                                                                                JET1063
        BO=VPL(IPL)
                                                                                                JET1064
        XTEMP(1)=XN(1)
                                                                                                JET1065
        DO 11 I=2,KN
XTEMP(I)=0.5D0*(XN(I)+XN(I-1))
                                                                                                JET1066
                                                                                                JET1067
                                                                                                JET1068
 11
        CONTINUE
        I=2
                                                                                                JET1069
        CALL INTERX(1, I, B0, BN, KN, XB0, XTEMP)
                                                                                                JET1070
        XPL(J, IPL)=XBO
                                                                                                JET1071
        GO TO 1001
                                                                                                JET1072
        CONTINUE
                                                                                                JET1073
    FIND BY INTERPOLATION THE X-COORDINATE WHERE M=MPL.
                                                                                                JET1074
        IF(J.GT.1) GO TO 200
                                                                                                JET1075
        XPL(J, IPL) = XC
                                                                                                JET1076
        GO TO 1001
                                                                                                JET1077
 200
        CONTINUE
                                                                                                JET1078
        MPL=VPL(IPL)
                                                                                                JET1079
        I = -KN
                                                                                                JET1080
```

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CALL INTERX(1,I,MPL,MN,KN,XM0,XN)
                                                                                       JET1081
      XPL(J, IPL)=XM0
                                                                                       JET1082
      GO TO 1001
                                                                                       JET1083
      CONTINUE
3
                                                                                       JET1084
  STREAMLINE INTERPOLATION. IF(J.GT.1) GO TO 300
                                                                                       JET1085
                                                                                       JET1086
     XPL(J, IPL)=VPL(IPL)
GO TO 1001
                                                                                       JET1087
                                                                                       JET1088
300
      CONTINUE
                                                                                       JET1089
      XSF=XPL(J-1, IPL)
                                                                                       JET1090
      ISF=2
                                                                                       JET1091
      ISN=2
                                                                                       JET1092
     CALL INTERP(0, ISF, KF, XSF, XF, RMSF, RMF, RPSF, RPF)
CALL RFUNC(RMSF, RPSF, MSF, MUSF, TETASF)
                                                                                       JET1093
                                                                                       JET1094
                                                                                       JET1095
      XSN=XSF+DY*DTAN(PAI2-TETASF)
                                                                                       JET1096
301
      ITER=ITER+1
                                                                                       JET1097
     CALL INTERP(1, ISN, KN, XSN, XN, RMSN, RMN, RPSN, RPN)
CALL RFUNC(RMSN, RPSN, MSN, MUSN, TETASN)
                                                                                       JET1098
                                                                                       JET1099
      TETAAV=0.5D0×(TETASF+TETASN)
                                                                                       JET1100
      XSN=XSF+DY*DTAN(PAI2-TETAAV)
                                                                                       JET1101
      IF(ITER.LT.ITER0+2) GO TO 301
                                                                                       JET1102
      XPL(J, IPL)=XSN
                                                                                       JET1103
      GO TO 1001
                                                                                       JET1104
      CONTINUE
                                                                                       JET1105
  CHARACTERISTIC LINE.
KC=IDINT(VPL(IPL)+1.D-5)
                                                                                       JET1106
                                                                                       JET1107
      IF(J.GT.1) GO TO 41
                                                                                       JET1108
      XPL(J, IPL)=XCHARF(KC)
                                                                                       JET1109
      GO TO 1001
                                                                                       JET1110
      CONTINUE
41
                                                                                       JET1111
      XPL(J, IPL) = XCHARN(KC)
                                                                                       JET1112
      IF(CSIGNN(KC).EQ.O.) XPL(J,IPL)=1.E33
                                                                                       JET1113
      GO TO 1001
                                                                                       JET1114
      CONTINUE
                                                                                       JET1115
  CONSTANT LATERAL (X) OPACITY
                                                                                       JET1116
      CALL OPACX
                                                                                       JET1117
      XIC=VPL(IPL)
                                                                                       JET1118
      DO 51 II=2,KF
I1=KF-II+1
                                                                                       JET1119
                                                                                       JET1120
                                                                                       JET1121
      I2=I1+1
                                                                                       JET1122
      XI1=XI(I1,JXI)
      XI2=XI(I2,JXI)
                                                                                       JET1123
      IF((XIC-XI1)*(XIC-XI2).GT.0.) GO TO 51
                                                                                       JET1124
      F2=(XI2-XIC)/(XI2-XI1)
                                                                                       JET1125
      F1=1.D0-F2
IF(F1.LT.0.) CALL FIN(1351)
                                                                                       JET1126
                                                                                       JET1127
      IF(F2.LT.0.) CALL FIN(1352)
                                                                                       JET1128
      XIFC=F2*XF(I1)+F1*XF(I2)
                                                                                       JET1129
      GO TO 52
                                                                                       JET1130
                                                                                       JET1131
51
      CONTINUE
      XIFC=1.D30
                                                                                       JET1132
                                                                                       JET1133
      CONTINUE
     XPL(J, IPL)=XIFC
GO TO 1001
                                                                                       JET1134
                                                                                       JET1135
                                                                                       JET1136
1001 CONTINUE
                                                                                       JET1137
      IF(J.GT.1) GO TO 1002
      YPL(J)=YC
                                                                                       JET1138
                                                                                       JET1139
      GO TO 1000
                                                                                       JET1140
1002 CONTINUE
                                                                                       JET1141
      YPL(J)=YN
                                                                                       JET1142
1000 CONTINUE
                                                                                       JET1143
      RETURN
                                                                    GRIDN
      END
                                                                                       JET1144
      SUBROUTINE GRIDN
                                                                                       JETI145
  SUBROUTINE NUMBER 14
                                                                                       JET1146
      IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                       JET1147
     REAL*4 XPL,YPL
COMMON /PLUME/XPL(1002,10),YPL(1002)
COMMON /IPLUME/KPL,ITYPL(10)
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
                                                                                       JET1148
                                                                                       JET1149
                                                                                       JET1150
                                                                                       JET1151
                      TETAF(101), BF(101),
                                                                                       JET1152
```

```
XN(101), RMN(101), RPN(101), MN(101), MUN(101),
                                                                                                                                                                          JET1153
                                                                                                                                                                          JET1154
                                             TETAN(101), BN(101), XTEMP(101)
             COMMON/THICKY/XTH(1002), TH(1002)
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1156
                                                                                                                                                                          JET1155
             COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
STAB, DELTA, PSII, PSIF, ZETA1, SIGMA, FRACG, EPSIL, NUO,
TETSYM, TETLIM, DDY, DYMAX
                                                                                                                                                                          JET1157
                                                                                                                                                                          JET1158
                                                                                                                                                                          JET1159
                                                                                                                                                                          JET1160
            2
              COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1
                                                                                                                                                                          JET1161
             COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,

KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD

COMMON /ROW/YF,YN,DXF,DXN

COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),

RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),

TOWNSON TOWN THE TOWN THE TOWN THE TOWN THE TOWN
                                                                                                                                                                          JET1162
                                                                                                                                                                          JET1163
                                                                                                                                                                          JET1164
                                                                                                                                                                          JET1165
                                                                                                                                                                         JET1166
                                                 TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
            2
                                                                                                                                                                          JET1167
            3
                                                 CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                                                                                                          JET1168
                                                 MCHARI(92)
                                                                                                                                                                          JET1169
      COMMON /ICHARA/KCHARP, KCHARM, KCHARO

DIVIDE LINE Y=YN INTO KN-1 INTERVALS.

THE X-GRID IS NON-UNIFORMLY DEFINED AS FOLLOWS:

(1) (XCHARN(I), YCHARN(I)), (XCHARF(I), YCHARF(I)), I=1,2,..., KCHARP, JET1173

DENOTE NEW AND OLD (FORMER) CHARACTERISTIC (C+) POINTS. LET I=1 JET1174

AND I=KCHARP CORRESPOND TO THE LEADING AND BOUNDARY

JET1175
CCCCCCCCCCCCCCCC
       CHARACTERISTICS (C+).

(2) THE GRID CONSISTS OF TWO SEGMENTS.
                                                                                                                                                                          JET1176
                THE GRID CONSISTS OF TWO SEGMENTS. THE SO-CALLED FLAT SEGMENT IS BETWEEN X=0 AND X=XLEAD=XCHARN(KCLEAD). THE SECOND IS THE
                                                                                                                                                                          JET1177
                                                                                                                                                                          JET1178
       FAN SEGMENT. IT IS FROM XLEAD TO XBOUND=XCHARN(KCHARP). JET1179

(3) THE FAN SEGMENT IS INITIALLY DIVIDED INTO FRACG*(KFO-1) INTERVALSJET1180
                DEFINED BY THE FAMILY OF C+ CHARACTERISTIC LINES MCHARI(1) TO
                                                                                                                                                                          JET1181
                                                                                                                                                                          JET1182
                MCHARI(KCHARP)
                                                                                                                                                                          JET1183
       (4) THE FLAT SEGMENT IS DIVIDED INTO (1-FRACG)*(KF0-1) EQUAL
                INTERVALS, AS LONG AS THEY ARE NOT SMALLER THAN THE AVERAGE FAN INTERVAL. WHEN THEY ARE, THEIR NUMBER IS REDUCED, BUT NOT
                                                                                                                                                                          JET1184
                                                                                                                                                                          JET1185
                BELOW THREE.
                                                                                                                                                                          JET1186
       (5) KCLEAD IS INITIALLY 1. IT IS UPDATED SO THAT IS AT LEAST TWICE THE AVERAGE FAN INTERVAL.
                                                                                                                                                                          JET1187
                                                                        IT IS UPDATED SO THAT THE FLAT SEGMENT
                                                                                                                                                                          JET1188
              ILEADF=ILEAD
                                                                                                                                                                          JET1189
                                                                                                                                                                          JET1190
              KCL EAD=0
                                                                                                                                                                          JET1191
              DO 1 KC=1,KCHARP
              IF(CSIGNN(KC).LT.0.) GO TO 1
                                                                                                                                                                          JET1192
              KCL EAD=KC
                                                                                                                                                                          JET1193
              KFAN=KCHARP-KCLEAD
                                                                                                                                                                          JET1194
              XLEAD=XCHARN(KCLEAD)
                                                                                                                                                                          JET1195
                                                                                                                                                                          JET1196
              XBOUND=XCHARN(KCHARP)
              DX1=(XBOUND-XLEAD)/DFLOAT(KFAN)
                                                                                                                                                                          JET1197
              IF(XLEAD/DX1.GT.2.D0) G0 TO 11
                                                                                                                                                                          JET1198
              CONTINUE
                                                                                                                                                                          JET1199
  īı
              CONTINUE
                                                                                                                                                                          JET1200
              IF(KCLEAD.EQ. 0) CALL FIN(1401) IF(KCLEAD.EQ.KCHARP) CALL FIN(1402)
                                                                                                                                                                          JET1201
                                                                                                                                                                          JET1202
              ILEAD=IDINT(XLEAD/DX1)+2
                                                                                                                                                                          JET1203
              IF(ILEAD+KFAN.GT.KF0) ILEAD=KF0-KFAN
                                                                                                                                                                          JET1204
                                                                                                                                                                          JET1205
              ILEAD1=ILEAD-1
              KN=ILEAD+KFAN
                                                                                                                                                                          JET1206
              IF(KN.GT.KF0) CALL FIN(1411)
                                                                                                                                                                          JET1207
              DX=XLEAD/DFLOAT(ILEAD1)
                                                                                                                                                                          JET1208
              XN(1)=0.
                                                                                                                                                                          JET1209
              DO 2 I=1, ILEAD1
                                                                                                                                                                          JET1210
              XN(I)=XN(1)+DX*DFLOAT(I-1)
                                                                                                                                                                          JET1211
                                                                                                                                                                          JET1212
JET1213
JET1214
  2
              CONTINUE
              DO 3 I=ILEAD, KN
              XN(I)=XCHARN(KCLEAD+I-ILEAD)
  3
              CONTINUE
                                                                                                                                                                          JET1215
                                                                                                                                        YSTEP
              RETURN
                                                                                                                                                                          JET1216
              END
                                                                                                                                                                          JET1217
              SUBROUTINE YSTEP
                                                                                                                                                                          JETIZI8
       SUBROUTINE NUMBER 15
                                                                                                                                                                          JET1219
              IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                                                                                                          JET1220
              REAL*4 XPL,YPL
COMMON /PLUME/XPL(1002,10),YPL(1002)
                                                                                                                                                                          JET1221
JET1222
              COMMON /IPLUME/KPL, ITYPL(10)
                                                                                                                                                                          JET1223
              COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
```

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TETAF(101), BF(101), XN(101), RMN(101), RMN(101), MUN(101), MUN(10
       1 2 3
                                                                                                                                                 JET1225
                                                                                                                                                 JET1226
                                    TETAN(101), BN(101), XTEMP(101)
                                                                                                                                                 JET1227
         COMMON/THICKY/XTH(1002), TH(1002)
                                                                                                                                                JET1228
         COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1229
                                    G16,G17,G18,G19,G20
                                                                                                                                                 JET1230
         COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT, STAB, DELTA, PSI1, PSIF, ZETA1, SIGMA, FRACG, EPSIL, NUO,
                                                                                                                                                 JET1231
                                                                                                                                                 JET1232
                                  TETSYM, TETLIM, DDY, DYMAX
                                                                                                                                                 JET1233
          COMMON /STAG/RHOO, NO, PO, TO, AO, MDOT1
                                                                                                                                                 JET1234
         COMMON /IPAR/JMAX,KFO,ITERO,KF,KN,IM,IP,J,
KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD
                                                                                                                                                 JET1235
                                                                                                                                                 JET1236
         COMMON /ROW/YF,YN,DXF,DXN
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),
                                                                                                                                                 JET1237
                                                                                                                                                 JET1238
                                        RMCARF(92), RPCARF(92), RMCARN(92), RPCARN(92), TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
                                                                                                                                                 JET1239
        23
                                                                                                                                                 JET1240
                                        CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                                                                                 JET1241
                                        MCHARI(92)
                                                                                                                                                 JET1242
          COMMON / ICHARA/KCHARP, KCHARM, KCHARO
                                                                                                                                                 JET1243
   COMPUTE NEXT Y-STEP.

JET1244
DYNEXT IS DEFINED AS THE MINIMAL "TRIANGULATION" Y-STEP DYT, OBTAINEDJET1245
    BY FORWARD INTERSECTION OF C-, C+ CHARACTERISTICS FROM ADJACENT GRID
                                                                                                                                                JET1246
   POINTS X1,X2.
                                                                                                                                                 JET1247
          DYMIN=1.D40
                                                                                                                                                 JET1248
          DO 1 I=3,KF
                                                                                                                                                 JET1249
          X1=XF(I-1)
                                                                                                                                                 JET1250
          X2=XF(I)
                                                                                                                                                 JET1251
          DX=X2-X1
                                                                                                                                                 JET1252
          TP1=DTAN(TETAF(I-1)-MUF(I-1))
                                                                                                                                                 JET1253
          TP2=DTAN(TETAF(I)+MUF(I))
                                                                                                                                                 JET1254
          F1=-TP2/(TP1-TP2)
                                                                                                                                                 JET1255
         IF(F1.LE.O.) PRINT 555,I,X1,X2,DX,TP1,TP2,F1
FORMAT(/1X,'I,X1,X2,DX,TP1,TP2,F1=',I5,6D14.6/)
IF(F1.LT.O.) CALL FIN(1501)
                                                                                                                                                 JET1256
555
                                                                                                                                                 JET1257
                                                                                                                                                 JET1258
                                                                                                                                                 JET1259
          DYT=F1*DX*TP1
          IF(DYT.LE.O.) CALL FIN(1502)
                                                                                                                                                 JET1260
          DYMIN=DMIN1(DYMIN, STAB*DYT)
                                                                                                                                                 JET1261
1
          CONTINUE
                                                                                                                                                 JET1262
          DYNEXT = DYMIN
                                                                                                                                                 JET1263
                                                                                                          MOVE
          RETURN
                                                                                                                                                 JET1264
                                                                                                                                                 JET1265
          END
          SUBROUTINE MOVE
                                                                                                                                                 JET1266
    SUBROUTINE NUMBER 16
IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                                                                                 JET1267
                                                                                                                                                 JET1268
          REAL * 4 XPL, YPL
                                                                                                                                                 JET1269
          COMMON /PLUME/XPL(1002,10), YPL(1002)
                                                                                                                                                 JET1270
          COMMON /IPLUME/KPL, ITYPL(10)
                                                                                                                                                 JET1271
          COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
                                                                                                                                                 JET1272
                                                                                                                                                 JET1273
                                     TETAF(101), BF(101),
                                    XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                                                                                 JET1274
                                                                                                                                                 JET1275
                                     TETAN(101), BN(101), XTEMP(101)
          COMMON/THICKY/XTH(1002),TH(1002)
                                                                                                                                                 JET1276
          COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1277
                                    G16,G17,G18,G19,G20
                                                                                                                                                 JET1278
          COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                                                                                 JET1279
                                  STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                                                                                 JET1280
                                   TETSYM, TETLIM, DDY, DYMAX
                                                                                                                                                 JET1281
                                                                                                                                                 JET1282
          COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1
          COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                                                                                 JET1283
                                    KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                                                                                 JET1284
          COMMON /ROW/YF, YN, DXF, DXN
COMMON /CHARAC/XCHARF(92), YCHARF(92), XCHARN(92), YCHARN(92),
                                                                                                                                                 JET1285
                                                                                                                                                 JET1286
                                         RMCARF(92), RPCARF(92), RMCARN(92), RPCARN(92),
                                                                                                                                                 JET1287
        2
3
                                         TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
                                                                                                                                                 JET1288
                                         CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                                                                                 JET1289
                                                                                                                                                 JET1290
                                        MCHARI (92)
                                                                                                                                                 JET1291
          COMMON /ICHARA/KCHARP, KCHARM, KCHARO
    STORE NEW LINE (N) IN OLD LINE (F).
                                                                                                                                                 JET1292
          KF=KN
                                                                                                                                                 JET1293
                                                                                                                                                 JET1294
          KF2=2×KF
          YF=YN
                                                                                                                                                 JET1295
                                                                                                                                                 JET1296
          DO 1 I=1,KN
```

```
XF(I)=XN(I)
                                                                                            JET1297
                                                                                            JET1298
      RMF(I)=RMN(I)
      RPF(I)=RPN(I)
                                                                                            JET1299
      MF(I)=MN(I)
                                                                                            JET1300
      MUF(I)=MUN(I)
                                                                                            JET1301
      TETAF(I)=TETAN(I)
                                                                                            JET1302
      BF(I)=BN(I)
                                                                                            JET1303
1
                                                                                            JET1304
      CONTINUE
      DO 2 KC=1,KCHARO
IF(CSIGNN(KC).EQ.O.) GO TO 2
                                                                                            JET1305
                                                                                            JET1306
      XCHARF(KC)=XCHARN(KC)
                                                                                            JET1307
      YCHARF(KC)=YCHARN(KC)
                                                                                            JET1308
      RMCARF(KC)=RMCARN(KC)
                                                                                            JET1309
      RPCARF(KC)=RPCARN(KC)
TCHARF(KC)=TCHARN(KC)
                                                                                            JET1310
                                                                                            JET1311
      MUCARF(KC)=MUCARN(KC)
                                                                                            JET1312
      MCHARF(KC)=MCHARN(KC)
                                                                                            JET1313
                                                                                            JET1314
      CSIGNF(KC)=CSIGNN(KC)
2
                                                                                            JET1315
      CONTINUE
                                                                                            JET1316
      RETURN
                                                                        OPACX
                                                                                            JET1317
JET1318
      END
      SUBROUTINE OPACX
  SUBROUTINE NUMBER 17
IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                            JET1319
                                                                                            JET1320
      REAL*4 XPL, YPL
                                                                                            JET1321
                                                                                            JET1322
      COMMON /PLUME/XPL(1002,10),YPL(1002)
      COMMON /IPLUME/KPL,ITYPL(10)
COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
                                                                                            JET1323
                                                                                            JET1324
                       TETAF(101), BF(101),
                                                                                            JET1325
                       XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                            JET1326
                       TETAN(101), BN(101), XTEMP(101)
                                                                                            JET1327
      COMMON/THICKY/XTH(1002), TH(1002)

REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF

COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20)

,XIAPP(101,20),XIF(101,20)
                                                                                            JET1328
                                                                                            JET1329
                                                                                            JET1330
                                                                                            JET1331
      COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1332
      G16,G17,G18,G19,G20
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DYO,DY,DYNEXT,
     1
                                                                                            JET1333
                                                                                            JET1334
                      STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                            JET1335
     1
                      TETSYM, TETLIM, DDY, DYMAX
                                                                                            JET1336
     2
      COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),
                                                                                            JET1337
                                                                                            JET1338
                         RMCARF(92), RPCARF(92), RMCARN(92), RPCARN(92), TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
                                                                                            JET1339
     2
3
                                                                                            JET1340
                         CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                            JET1341
                                                                                            JET1342
                         MCHARI(92)
                                                                                            JET1343
      COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
      KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD COMMON / ROW/YF, YN, DXF, DXN
                                                                                            JET1344
                                                                                            JET1345
  COMPUTE X-OPACITY.
                                                                                            JET1346
  BEGIN FROM LIMITING CHARACTERISTIC OF AN ASSUMED P.M. FAN.
XIO -- THE THICKNESS BETWEEN THE LIMITING CHARACTERISTIC AND THE
BOUNDARY CHARACTERISTIC OF THE NUMERICAL COMPUTATION.
                                                                                            JET1347
                                                                                            JET1348
                                                                                            JET1349
                                                                                            JET1350
      DO 12 I=1,KF0
      XIF(I,JXI)=XF(I)
                                                                                            JET1351
      XI(I,JXI)=0.
                                                                                            JET1352
      XIPM(I,JXI)=0.
                                                                                            JET1353
      XIGRP(I,JXI)=0.
                                                                                            JET1354
      XIAPP(I,JXI)=0.
                                                                                            JET1355
12
                                                                                            JET1356
      CONTINUE
      IF(J.EQ.1) GO TO 1000
                                                                                            JET1357
      PSILIM=TETLIM
                                                                                            JET1358
      XLIM=XC+(YF-YC)/DTAN(PSILIM)
                                                                                            JET1359
      XBOUND=XF(KF)
                                                                                            JET1360
                                                                                            JET1361
      KPM=10
      DX=(XLIM-XBOUND)/DFLOAT(KPM)
                                                                                            JET1362
      SUM=0.
                                                                                            JET1363
      DO 1 I=1,KPM
                                                                                            JET1364
      X1=XBOUND+DFLOAT(I-1)*DX
                                                                                            JET1365
                                                                                            JET1366
      X2=X1+DX
      PS1=PAI2-DATAN((X1-XC)/(YF-YC))
                                                                                            JET1367
      PS2=PAI2-DATAN((X2-XC)/(YF-YC))
                                                                                            JET1368
```

```
Q1=(PS1-PSILIM)/G5
                                                                                JET1369
     Q2=(PS2-PSILIM)/G5
                                                                                JET1370
     IF(I.EQ.KPM) Q2=1.D-10
                                                                                JET1371
     IF(Q2.LT.0.) CALL FIN(1701)
                                                                                JET1372
     F1=G11*(DSIN(Q1))**(2.D0/(G-1.D0))
                                                                                JET1373
     F2=G11*(DSIN(Q2))**(2.D0/(G-1.D0))
                                                                                JET1374
     SUM=SUM+DX*(F1+F2)/2.D0
                                                                                 JET1375
1
     CONTINUE
                                                                                JET1376
     XIO=SUM*(NO*SIGMA)
                                                                                 JET1377
  RE-EVALUATE XIO FOR A RING-JET. IF(DELTA.EQ.O.) GO TO 14
                                                                                JET1378
                                                                                 JET1379
     M=MFIN
                                                                                 JET1380
     CALL MFUNC(M, F, ETA, TETA)
                                                                                 JET1381
     PSI=TETA+DARSIN(1.D0/M)
                                                                                 JET1382
     GOREM=1.D0+G1*M**2
                                                                                 JET1383
     GOR=M**2-1.D0
                                                                                 JET1384
     CALL HINTER(M, HM)
                                                                                 JET1385
     DELTOB=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1386
         +G15×HM/2.D0
                                                                                 JET1387
     EVER=SIGMA*NO*YC/(M*DSIN(TETA)*DSIN(PSI)*GOREM**G6)
                                                                                 JET1388
     GGG=2.D0-DELT0B*(G+1.D0)/2.D0
                                                                                 JET1389
     IF(DABS(GGG).GT.1.D-10) GO TO 15
                                                                                 JET1390
     PRINT 16, DELTOB, G, GGG
FORMAT(/1X, FROM OPACX. GGG NEARLY ZERO. EXPRESSION FOR XIO IS',
                                                                                JET1391
16
                                                                                JET1392
              1X, 'SINGULAR. DELTOB, G, GGG=', 3D12.4/)
                                                                                 JET1393
          FIN(1715)
                                                                                 JET1394
     CONTINUE
15
                                                                                 JET1395
     EVER = EVER/GGG
                                                                                JET1396
     XIO=EVER*((YF/YC)**GGG-1.D0)/(YF/YC)
                                                                                 JET1397
14
     CONTINUE
                                                                                 JET1398
     XI(KF, JXI) = XIO
                                                                                JET1399
                                                                                JET1400
     XIPM(KF, JXI) = XIO
     XIGRP(KF, JXI) = XIO
                                                                                 JET1401
     KF1=KF-1
                                                                                 JET1402
     DO 2 II=1,KF1
I=KF-II+1
                                                                                 JET1403
                                                                                 JET1404
     X1=XF(I)
                                                                                JET1405
     X2=XF(I-1)
                                                                                 JET1406
     DX=X1-X2
                                                                                 JET1407
     F1=1.D0/(1.D0+G1*MF(I )**2)**G6
                                                                                JET1408
     F2=1.D0/(1.D0+G1*MF(I-1)**2)**G6
                                                                                JET1409
     DTNUM=(N0*SIGMA)*DX*(F1+F2)/2.D0
                                                                                JET1410
     XI(I-1,JXI)=XI(I,JXI)+DTNUM
                                                                                 JET1411
     XIPM(I-1,JXI)=1.D24
                                                                                 JET1412
     XIGRP(I-1,JXI)=1.D24
                                                                                JET1413
     PS1=PAI2-DATAN((X1-XC)/(YF-YC))
                                                                                JET1414
     PS2=PAI2-DATAN((X2-XC)/(YF-YC))
                                                                                JET1415
     IF(PS2.GT.PSI1) GO TO 2
                                                                                 JET1416
     Q1=(PS1-PSILIM)/G5
                                                                                JET1417
     Q2=(PS2-PSILIM)/G5
                                                                                JET1418
     IF(Q1.LT.0.) CALL FIN(1711)
                                                                                JET1419
     F1=G11*(DSIN(Q1))**(2.D0/(G-1.D0))
F2=G11*(DSIN(Q2))**(2.D0/(G-1.D0))
DTPM=(N0*SIGMA)*DX*(F1+F2)/2.D0
                                                                                 JET1420
                                                                                 JET1421
                                                                                 JET1422
     XIPM(I-1,JXI)=XIPM(I,JXI)+DTPM
                                                                                JET1423
     DIST1=DSQRT((X1-XC)**2+(YF-YC)**2)
                                                                                 JET1424
     DIST2=DSQRT((X2-XC)**2+(YF-YC)**2)
                                                                                 JET1425
     KC1=KCLEAD+I-ILEAD
                                                                                JET1426
     KC2=KC1-1
                                                                                 JET1427
     IF(KC2.LT.KCLEAD) GO TO 21
                                                                                 JET1428
     M1=MCHARI(KC1)
                                                                                 JET1429
     M2=MCHARI(KC2)
                                                                                 JET1430
     CALL MATCH(I ,M1,MG1,M0BI1,MABI1)
CALL MATCH(I-1,M2,MG2,M0BI2,MABI2)
                                                                                 JET1431
                                                                                JET1432
     F1=1.D0/(1.D0+G1*MG1**2)**G6
                                                                                 JET1433
     F2=1.D0/(1.D0+G1*MG2**2)**G6
                                                                                 JET1434
     DTGRP=(N0*SIGMA)*DX*(F1+F2)/2.D0
                                                                                JET1435
     XIGRP(I-1,JXI)=XIGRP(I,JXI)+DTGRP
                                                                                 JET1436
     CONTINUE
21
                                                                                 JET1437
     CONTINUE
                                                                                JET1438
  APPROXIMATE THICKNESS XIAPP(I, JXI). BASED ON CLOSED-FORM INTEGRATION. JET1439
     DO 3 I=1,KF
                                                                                 JET1440
```

```
XIAPP(I, JXI)=1.D24
                                                                                        JET1441
      KC=KCLEAD+(I-ILEAD)
                                                                                        JET1442
      IF(DELTA.EQ.O.) GO TO 3
                                                                                        JET1443
      IF(KC.LT.KCLEAD) GO TO 3
                                                                                        JET1444
JET1445
      IF(XF(I).LT.XCHARF(1)) GO TO 3
      M=MCHARI(KC)
                                                                                        JET1446
      CALL MFUNC(M,F,ETA,TETA)
PSI=TETA+DARSIN(1.D0/M)
                                                                                        JET1447
                                                                                        JET1448
      GOREM=1.D0+G1*M**2
                                                                                        JET1449
                                                                                        JET1450
      GOR=M**2-1.DO
      CALL HINTER(M, HM)
                                                                                        JET1451
      DELTOB=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI)
                                                                                        JET1452
         +G15*HM/2.D0
                                                                                        JET1453
      EVER=SIGMA*NO*YC/(M*DSIN(TETA)*DSIN(PSI)*GOREM**G6)
                                                                                        JET1454
      GGG=2.D0-DELT0B*(G+1.D0)/2.D0
                                                                                        JET1455
      IF(DABS(GGG).GT.1.D-10) GO TO 25
                                                                                        JET1456
     PRINT 26, I,KC,M,DELTOB,G,GGG
FORMAT(/1X,'FROM OPACX. GGG NEARLY ZERO. EXPRESSION FOR XIO IS',
1X,'SINGULAR. I,KC,M=',I5,D12.4/
                                                                                        JET1457
26
                                                                                        JET1458
                                                                                        JET1459
                1X, 'DELTOB, G, GGG=', 3D12.4/)
     2
                                                                                        JET1460
      CALL FIN(1725)
                                                                                        JET1461
      CONTINUE
25
                                                                                        JET1462
                                                                                        JET1463
      EVER=EVER/GGG
      XIAPP(I,JXI)=EVER*((YF/YC)**GGG-1.D0)/(YF/YC)
                                                                                        JET1464
      CONTINUE
                                                                                        JET1465
1000 CONTINUE
                                                                                        JET1466
      RETURN
                                                                                        JET1467
                                                                LOADC
                                                                                         JET1468
      END
      SUBROUTINE LOADC
                                                                                        JET1469
  SUBROUTINE NUMBER 18
IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                        JET1470
                                                                                        JET1471
      REAL*4 XPL, YPL
                                                                                        JET1472
      COMMON /PLUME/XPL(1002,10), YPL(1002)
                                                                                        JET1473
      COMMON /IPLUME/KPL, ITYPL(10)
                                                                                        JET1474
      COMMON /VECS/XF(101),RMF(101),RPF(101),MF(101),MUF(101),
                                                                                        JET1475
                      TETAF(101), BF(101),
                                                                                        JET1476
     23
                      XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                        JET1477
                      TETAN(101), BN(101), XTEMP(101)
                                                                                        JET1478
      COMMON/THICKY/XTH(1002), TH(1002)
                                                                                         JET1479
      REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF
COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20)
                                                                                        JET1480
                                                                                        JET1481
                       ,XIAPP(101,20),XIF(101,20)
                                                                                        JET1482
      COMMON / GAMA/G, G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, G12, G13, G14, G15, JET1483
     1
                      G16,G17,G18,G19,G20
                                                                                        JET1484
      COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT, STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                        JET1485
                                                                                        JET1486
     2
                     TETSYM, TETLIM, DDY, DYMAX
                                                                                        JET1487
      COMMON /STAG/RHO0,N0,P0,T0,A0,MDOT1
                                                                                        JET1488
      COMMON / IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                        JET1489
                      KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
      COMMON /ROW/YF,YN,DXF,DXN
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),
RMCARF(92),RPCARF(92),RMCARN(92),RPCARN(92),
RMCARF(92),RMCARN(92),MUCARF(92),MUCARN(92),
                                                                                        JET1490
                                                                                        JET1491
                                                                                        JET1492
     1
                                                                                        JET1493
     2
                         TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
                                                                                        JET1494
                         CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                        JET1495
                         MCHARI(92)
                                                                                        JET1496
      COMMON /ICHARA/KCHARP, KCHARM, KCHARO
                                                                                        JET1497
  LOAD FLOW VARIABLES OF GRID POINTS IN THE FAN SEGMENT FROM THE SEMI-INVERSE INTEGRATION (IN SUBR. SEMINV). NOTE THAT GRID POINTS
                                                                                        JET1498
                                                                                        JET1499
  XN(I) WERE ALREADY DETERMINED IN SUBR. GRIDN.
                                                                                        JET1500
      DO 1 I=ILEAD, KN
                                                                                        JET1501
      KC=KCLEAD+I-ILEAD
                                                                                        JET1502
      IF(KC.GT.KCHARP) CALL FIN(1801)
                                                                                        JET1503
      RMN(I)=RMCARN(KC)
                                                                                        JET1504
      RPN(I)=RPCARN(KC)
                                                                                        JET1505
      MN(I)=MCHARN(KC)
                                                                                        JET1506
      MUN(I)=MUCARN(KC)
                                                                                        JET1507
                                                                                        JET1508
      TETAN(I)=TCHARN(KC)
1
      CONTINUE
                                                                                        JET1509
      RETURN
                                                                                        JET1510
                                                             NUFUNC
                                                                                        JET1511
      DOUBLE PRECISION FUNCTION NUFUNC(M)
                                                                                        JETI512
```

```
SUBROUTINE NUMBER 19
                                                                                JET1513
   IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                JET1514
   REAL*4 XPL, YPL
                                                                                JET1515
   COMMON /PLUME/XPL(1002,10), YPL(1002)
                                                                                JET1516
   COMMON /IPLUME/KPL, ITYPL(10)
                                                                                JET1517
   COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                                                                                JFT1518
                  TETAF(101), BF(101),
                                                                                JET1519
  23
                  XN(101),RMN(101),RPN(101),MN(101),MUN(101),
                                                                                JET1520
                   TETAN(101), BN(101), XTEMP(101)
                                                                                JET1521
   COMMON/THICKY/XTH(1002),TH(1002)
                                                                                JET1522
   REAL*4 YXI,XI,XIPM,XIGRP,XIAPP,XIF
                                                                                JET1523
   COMMON /THICKX/YXI(20),XI(101,20),XIPM(101,20),XIGRP(101,20)
                                                                                JET1524
   XIAPP(101,20),XIF(101,20) JET1525
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1526
  1
                  G16,G17,G18,G19,G20
                                                                                JET1527
   COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                JET1528
                 STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
  1
                                                                                JET1529
  2
                 TETSYM, TETLIM, DDY, DYMAX
                                                                                JET1530
   COMMON /STAG/RHOO,NO,PO,TO,AO,MDOT1
                                                                                JET1531
   COMMON / IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                JET1532
                  KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                JET1533
   COMMON /ROW/YF,YN,DXF,DXN
COMMON /CHARAC/XCHARF(92),YCHARF(92),XCHARN(92),YCHARN(92),
                                                                                JET1534
                                                                                JET1535
                     RMCARF(92), RPCARF(92), RMCARN(92), RPCARN(92),
                                                                                JET1536
  23
                     TCHARF(92), TCHARN(92), MUCARF(92), MUCARN(92),
                                                                                JET1537
                     CSIGNN(92), CSIGNF(92), MCHARN(92), MCHARF(92),
                                                                                JET1538
                     MCHARI(92)
                                                                                JET1539
COMMON /ICHARA/KCHARP,KCHARM,KCHARO
COMPUTE NU AS FUNCTION OF MACH NUMBER M. NOTE THAT THE P.M.
DEFINITION OF NU HAS BEEN MODIFIED BY ADDING A CONSTANT. THE USUAL
                                                                                JET1540
                                                                                JET1541
                                                                                JET1542
CHOICE OF THE CONSTANT IS SUCH THAT NU=0 FOR INFINITE M.
                                                                                JET1543
   Q=1.D0/DSQRT(M**2-1.D0)
                                                                                JET1544
   NUFUNC=NUO-(G5*DATAN(G5*Q)-DATAN(Q))
                                                                                JET1545
   RETURN
                                                                                JET1546
                                                             HMSET
                                                                                 JET1547
   END
   SUBROUTINE HMSET
                                                                                JET1548
SUBROUTINE NUMBER 20
IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                JET1549
                                                                                JET1550
   REAL *8 KAPAOB
                                                                                JET1551
   COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1552
                  G16,G17,G18,G19,G20
                                                                                JET1553
   COMMON /PAR/PAI, PAI2, DEG, XC, YC, MEXIT, MFIN, YMAX, DYO, DY, DYNEXT,
                                                                                JET1554
                 STAB, DELTA, PSII, PSIF, ZETAI, SIGMA, FRACG, EPSIL, NUO,
                                                                                JET1555
  2
                 TETSYM, TETLIM, DDY, DYMAX
                                                                                JET1556
   COMMON / IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                JET1557
                                                                                JET1558
                  KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
  1
   COMMON /GRP/DMINV, MHINV(101), HMV(101)
                                                                                JET1559
   COMMON / IGRP/KHM
                                                                                JET1560
A ROUTINE FOR THE C+ DERIVATIVE DUE TO RING SYMMETRY (GRP).
                                                                                JET1561
                                                                                JET1562
   KHM=51
   IF(KHM.GT.101) CALL FIN(2001)
                                                                                JET1563
   MINV0=1.D0/MEXIT
                                                                                JET1564
   DMINV=MINVO/DFLOAT(KHM-1)
                                                                                 JET1565
   M=MEXIT
                                                                                JET1566
                                                                                JET1567
   SUM=0
   KHM1=KHM-1
                                                                                JET1568
                                                                                JET1569
   DO 1 I=1,KHM1
   MF=M
                                                                                JET1570
   MHINV(I)=MINVO-DFLOAT(I-1)*DMINV
                                                                                JET1571
                                                                                JET1572
   M=1.D0/MHINV(I)
   DM=M-MF
                                                                                JET1573
                                                                                 JET1574
   M1=M-DM
   M2=M-DM/2.D0
                                                                                JET1575
                                                                                 JET1576
   M3=M
                                                                                JET1577
   CALL MFUNC(M1,F1,ETA1,TETA1)
                                                                                JET1578
   CALL MFUNC(M2,F2,ETA2,TETA2)
   CALL MFUNC(M3,F3,ETA3,TETA3)
                                                                                JET1579
   SUM=SUM+DM*(F1+4.D0*F2+F3)/6.D0
                                                                                JET1580
                                                                                JET1581
   ETA=ETA3
                                                                                JET1582
   TETA=TETA3
                                                                                 JET1583
   PSI=TETA+DARSIN(1.D0/M)
   NORM = ((3.D0-G)/4.D0) \times (M \times 2 - 1.D0) \times 0.75D0/
                                                                                JET1584
```

```
(DSIN(PSI)*(1.D0+G1*M**2)**G14)
                                                                                              JET1585
       HM=SUM*NORM
                                                                                              JET1586
       HMV(I)=HM
                                                                                              JET1587
       GOREM=1.D0+G1*M**2
                                                                                              JET1588
       GOR=M**2-1.DO
                                                                                              JET1589
       DELTOB=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1590
                                                                                              JET1591
           +((G+1.D0)/(2.D0*(3.D0-G)))*HM
       EPSIOB=DELTOB/DSQRT(GOR)-DSIN(TETA)/(M*DSIN(PSI))
                                                                                              JET1592
                                                                                              JET1593
       KAPA0B=1.D0
                                                                                              JET1594
       IF(DABS(PAI2-TETA).GT.1.D-6)
      1KAPAOB=DTAN(TETA) * EPSIOB
                                                                                              JET1595
       LAMDOB=EPSIOB-DELTOB*GOREM/(GOR*DSQRT(GOR))
                                                                                              JET1596
       PRINT 11, I, M, HM, TETA*DEG, PSI*DEG
                                                                                              JET1597
       FORMAT(/1X, I, M, HM, TETA, PSI=1, 15,5D12.4)
PRINT 12, DELTOB, EPSIOB*DEG, KAPAOB*DEG, LAMDOB*DEG
FORMAT( 1X, DELTOB, EPSIOB, KAPAOB, LAMDOB=1,5X,5D12.4)
                                       I,M,HM,TETA,PSI=",I5,5D12.4)
                                                                                              JET1598
 11
                                                                                              JET1599
                                                                                              JET1600
 12
       CONTINUE
                                                                                              JET1601
                                                                                              JET1602
       MHINV(KHM)=0
       HMV(KHM)=1.D0
                                                                                              JET1603
       RETURN
                                                                                              JET1604
                                                                      MFUNC
                                                                                              JET1605
       END
        SUBROUTINE MFUNC(M, F, ETA, TETA)
                                                                                              JET1606
    SUBROUTINE NUMBER 21
                                                                                              JET1607
C
       IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                              JET1608
       COMMON /GAMA/G, G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, G12, G13, G14, G15, JET1609
       G16,G17,G18,G19,G20

COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,
STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,
                                                                                              JET1610
                                                                                              JET1611
                                                                                              JET1612
      1
                       NUPT1, TETLIM
                                                                                               JET1613
      2
       COMMON /IPAR/JMAX,KF0,ITER0,KF,KN,IM,IP,J,
KF2,IDEL,JDEL,JYXI,JXI,ILEAD,ILEADF,KCLEAD
COMMON /GRP/DMINV,MHINV(101),HMV(101)
                                                                                              JET1614
                                                                                              JET1615
                                                                                              JET1616
                                                                                              JET1617
C
       NU=NUFUNC(M)
                                                                                              JET1618
       TETA=NUFUNC(MEXIT)+PAI2-NU
                                                                                              JET1619
                                                                                              JET1620
       GOREM=1.D0+G1*M**2
       GOR=M**2-1.DO
                                                                                              JET1621
       F=(M**2)*(GOREM**G13)*DSIN(TETA)/GOR**1.25D0
                                                                                               JET1622
                                                                                              JET1623
       GOREM1=1.D0+G1*MEXIT**2
                                                                                               JET1624
       GOR1=MEXIT**2-1.D0
       ETA=((GOREM/GOREM1)**G14)*((GOR1/GOR)**0.25D0)
                                                                                              JET1625
       RETURN
                                                                                               JET1626
        END
                                                                                               JET1627
        SUBROUTINE HINTER(M,H)
                                                                                               JET1628
   SUBROUTINE NUMBER 22
IMPLICIT REAL*8(A-H,L-Z,$)
                                                                                               JET1629
                                                                                               JET1630
        COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1631
       G16,G17,G18,G19,G20
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DYO,DY,DYNEXT,STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NUO,
      1
                                                                                              JET1632
                                                                                              JET1633
                                                                                               JET1634
      1
                       TETSYM, TETLIM, DDY, DYMAX
                                                                                               JET1635
       COMMON / IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
                                                                                               JET1636
       KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD COMMON / GRP/DMINV, MHINV(101), HMV(101)
      1
                                                                                               JET1637
                                                                                               JET1638
        COMMON / IGRP/KHM
                                                                                               JET1639
C COMPUTE H(M) BY INTERPOLATION
                                                                                               JET1640
       MINV=1.DO/M
I=KHM-IDINT(MINV/DMINV-1.D-9)-1
                                                                                               JET1641
                                                                                               JET1642
       IF(I.GE.1.AND.I.LT.KHM) GO TO 1
PRINT 11,I,KHM,M,MEXIT
FORMAT(/1X,'I,KHM,M,MEXIT=',215,2D14.6/)
CALL FIN(2201)
                                                                                               JET1643
                                                                                               JET1644
 11
                                                                                               JET1645
                                                                                               JET1646
        CONTINUE
 1
                                                                                               JET1647
        F1=(MINV-MHINV(I+1))/DMINV
                                                                                               JET1648
        F2=1.D0-F1
                                                                                               JET1649
       IF(F1.LT.-1.D-9) CALL FIN(2210)
IF(F2.LT.-1.D-9) CALL FIN(2211)
H=F1*HMV(I)+F2*HMV(I+1)
                                                                                               JET1650
                                                                                               JET1651
                                                                                               JET1652
        RETURN
                                                                                               JET1653
                                                                     MATCH
                                                                                               JET1654
        END
        SUBROUTINE MATCH(I, MOB, MAB, MOBI, MABI)
                                                                                              JET1655
```

SUBROUTINE NUMBER 23

```
IMPLICIT REAL ×8(A-H, L-Z, $)
                                                                                   JET1657
       COMMON /VECS/XF(101), RMF(101), RPF(101), MF(101), MUF(101),
                                                                                   JET1658
                      TETAF(101), BF(101),
XN(101), RMN(101), RPN(101), MN(101), MUN(101),
                                                                                   JET1659
      2
3
                                                                                   JET1660
                      TETAN(101), BN(101), XTEMP(101)
                                                                                   JET1661
       COMMON / ROW/YF, YN, DXF, DXN
                                                                                   JET1662
       COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1663
      G16,G17,G18,G19,G20
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DYO,DY,DYNEXT,
STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NUO,
                                                                                   JET1664
                                                                                   JET1665
                                                                                   JET1666
      2
                     TETSYM, TETLIM, DDY, DYMAX
                                                                                   JET1667
       COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,
KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD
                                                                                   JET1668
      1
                                                                                   JET1669
       COMMON /GRP/DMINV, MHINV(101), HMV(101)
                                                                                   JET1670
       COMMON / IGRP/KHM
                                                                                   JET1671
C COMPUTE H(M) AND THE ALFA-DERIVATIVES
                                                                                   JET1672
      M=MOB
                                                                                   JET1673
       CALL MFUNC(M, F, ETA, TETA)
                                                                                   JET1674
       PSI=TETA+DARSIN(1.DO/M)
                                                                                   JET1675
       CALL HINTER(M, HM)
                                                                                   JET1676
       GOREM=1.D0+G1*M**2
                                                                                   JET1677
       GOR=M**2-1.DO

JET1678
DELTOB=0.5DO*DSQRT(GOR)*(1.DO/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1679
          +G15×HM/2.D0
                                                                                   JET1680
       FOB=(G7*GOREM)**G2/M
                                                                                   JET1681
       FAB=FOB*(YF/YC)**DELTOB
                                                                                   JET1682
       CALL AREAF(FAB, MAB)
                                                                                   JET1683
                                                                                   JET1684
   COMPUTE MABI FROM THE INVERSE PROBLEM SOLUTION
       COTAV=(XF(I)-XC)/(YF-YC)
                                                                                   JET1685
       PSIO=PAI2-DATAN(COTAV)
                                                                                   JET1686
       EVY=YF*DLOG(YF/YC)/(YF-YC)-1.DO
                                                                                   JET1687
       PSIN=PSIO
                                                                                   JET1688
       DO 1 ITER=1,50
                                                                                   JET1689
       PSI=PSIN
                                                                                   JET1690
       M=DSQRT(1.D0+G4/DTAN((PSI-TETLIM)/G5)**2)
                                                                                   JET1691
      M=DMAX1(M, MEXIT)
                                                                                   JET1692
                                                                                   JET1693
       CALL HINTER(M, HM)
       CALL MFUNC(M,F,ETA,TETA)
                                                                                   JET1694
       GOREM=1.D0+G1*M**2
                                                                                   JET1695
       GOR=M**2-1.DO

DELTOB=0.5DO*DSQRT(GOR)*(1.DO/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1697
          +G15×HM/2.D0
                                                                                   JET1698
       EPSIOB=DELTOB/DSQRT(GOR)-DSIN(TETA)/(M*DSIN(PSI))
                                                                                   JET1699
       LAMDOB=EPSIOB-DELTOB*GOREM/(GOR*DSQRT(GOR))
                                                                                   JET1700
       COTN=COTAV+LAMDOB*EVY/DSIN(PSI)**2
                                                                                   JET1701
       PSIN=PAI2-DATAN(COTN)
                                                                                   JET1702
       DPSI=PSIN-PSI
                                                                                   JET1703
       IF(DABS(DPSI).LT.1.D-9) GO TO 11
                                                                                   JET1704
                                                                                   JET1705
 1
       CONTINUE
       PRINT 12, I, ITER, PSI, PSIN, DPSI, M, XF(I), YF, XC, YC
                                                                                   JET1706
       FORMAT(/1X, 'I, ITER, PSI, PSIN, DPSI, M, XF(I), YF, XC, YC='//
1X, 2I4, 8D11.3/)
 12
                                                                                   JET1707
                                                                                   JET1708
       CALL FIN(2301)
                                                                                   JET1709
       CONTINUE
                                                                                   JET1710
 11
   USING MOBI M AS COMPUTED FROM THE INVERSE PROBLEM, FIND MABI.
                                                                                   JET1711
       MOBI=M
                                                                                   JET1712
                                                                                   JET1713
       M=MOBI
       CALL MFUNC(M, F, ETA, TETA)
                                                                                   JET1714
                                                                                   JET1715
       PSI=TETA+DARSIN(1.D0/M)
                                                                                   JET1716
       CALL HINTER(M, HM)
       GOREM=1.D0+G1*M**2
                                                                                   JET1717
       GOR=M**2-1.D0 JET1718
DELTOB=0.5D0*DSQRT(GOR)*(1.D0/(MEXIT*ETA)+DSIN(TETA)/M)/DSIN(PSI) JET1719
          +G15×HM/2.D0
                                                                                   JET1720
       FOB=(G7*GOREM)**G2/M
                                                                                   JET1721
       FAB=FOB*(YF/YC)**DELTOB
                                                                                    JET1722
       CALL AREAF(FAB, MABI)
                                                                                    JET1723
       RETURN
                                                              AREAF
                                                                                    JET1724
       END
                                                                                    JET1725
       SUBROUTINE AREAF(F,M)
                                                                                   JET1726
   SUBROUTINE NUMBER 24
                                                                                    JET1727
C
```

IMPLICIT REAL ×8(A-H,L-Z,\$)

```
COMMON /GAMA/G,G1,G2,G3,G4,G5,G6,G7,G8,G9,G10,G11,G12,G13,G14,G15,JET1729
        G16,G17,G18,G19,G20
COMMON /PAR/PAI,PAI2,DEG,XC,YC,MEXIT,MFIN,YMAX,DY0,DY,DYNEXT,
STAB,DELTA,PSI1,PSIF,ZETA1,SIGMA,FRACG,EPSIL,NU0,
TETSYM,TETLIM,DDY,DYMAX
                                                                                                 JET1730
                                                                                                 JET1731
                                                                                                 JET1732
       1
       2
                                                                                                 JET1733
        COMMON /IPAR/JMAX, KFO, ITERO, KF, KN, IM, IP, J,

KF2, IDEL, JDEL, JYXI, JXI, ILEAD, ILEADF, KCLEAD

COMMON /GRP/DMINV, MHINV(101), HMV(101)
                                                                                                 JET1734
                                                                                                 JET1735
       1
                                                                                                 JET1736
        COMMON / IGRP/KHM
                                                                                                 JET1737
    COMPUTE MACH NUMBER M FROM AREA RATIO FUNCTION F
                                                                                                 JET1738
    F=((2/(G+1))*(1+(G-1)*M**2))**((G+1)/(2*(G-1)))/M
                                                                                                 JET1739
    INITIAL GUESS IS MIN
E1=(F*MEXIT)**(1.D0/G2)/G7
                                                                                                 JET1740
                                                                                                 JET1741
        E2=(E1-1.D0)/G1
                                                                                                 JET1742
        E3=DMAX1(E2, MEXIT**2)
                                                                                                 JET1743
        MIN=DSQRT(E3)
                                                                                                 JET1744
        EMN=MIN
                                                                                                 JET1745
        DO 1 I=1,100
EMO=EMN
                                                                                                 JET1746
                                                                                                 JET1747
        GOREM=1.D0+G1*EM0**2
                                                                                                 JET1748
        GOR=EMO**2-1.DO
                                                                                                 JET1749
        FO=(G7*GOREM)**G2/EMO
                                                                                                 JET1750
        DF=FO-F
PRINT 123,I,EMO,EMN,FO,F,DF,GOR,GOREM
FORMAT(1X,'I,EMO,EMN,FO,F,DF,GOR,GOREM=',I5,7D12.4)
                                                                                                 JET1751
C
C123
                                                                                                 JET1752
                                                                                                 JET1753
        DFDM=F0*GOR/(EM0*GOREM)
                                                                                                 JET1754
        DMN=DF/DFDM
                                                                                                 JET1755
        EMN=EMO-DMN
                                                                                                 JET1756
        EPSEM=DABS(DMN/EMN)
                                                                                                 JET1757
        IF(EPSEM.LT.1.D-10) GO TO 11
                                                                                                 JET1758
 1
        CONTINUE
                                                                                                 JET1759
        CALL FIN(2401)
                                                                                                 JET1760
        CONTINUE
                                                                                                 JET1761
 11
        M=EMN
                                                                                                 JET1762
        RETURN
                                                                                                 JET1763
        END
                                                                                                 JET1764
```

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